Effects of Pre-treatments on Drying Characteristics of Bitter gourd

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Effects of Pre-treatments on Drying Characteristics of Bitter gourd

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by

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under the supervision of

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This is to certify that the work presented in this dissertation entitled *Effects of Pre-treatments on Drying Characteristics of Bitter gourd* by *A. Srimagal*, Roll Number *614FT3001*, is a record of original research carried out by her under my supervision and guidance in partial fulfilment of the requirements of the degree of *Master of Technology (Research)* in *Food Process Engineering*. Neither this dissertation nor any part of it has been submitted for any degree or diploma to any institute or university in India or abroad.

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Dedicated to my

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Declaration of Originality

I, *A. Srimagal*, Roll Number *614FT3001* hereby declare that this dissertation entitled *Effects of Pre-treatments on Drying Characteristics of Bitter gourd* represents my original work carried out as a post graduate student of NIT Rourkela and, to the best of my knowledge, it contains no material previously published or written by another person, nor any material presented for the award of any other degree or diploma of NIT Rourkela or any other institution. Any contribution made to this research by others, with whom I have worked at NIT Rourkela or elsewhere, is explicitly acknowledged in the dissertation. Works of other authors cited in this dissertation have been duly acknowledged under the sections "Reference". I have also submitted my original research records to the scrutiny committee for evaluation of my dissertation.

I am fully aware that in case of any non-compliance detected in future, the Senate of NIT Rourkela may withdraw the degree awarded to me on the basis of the present dissertation.

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Abstract

Bitter gourd (*Momordica charantia L.*) is an internationally consumed vegetable containing high amounts of vitamins (C, A and E) and minerals (phosphorus, potassium, and calcium). It has many medicinal properties like anti-diabetic, anti-infective, antipyretic, anthelmintic, antifungal, androgenic, antiviral, antimalarial actions and is widely recommended in daily diet. Despite of many advantages, proper processing and value addition have not been explored yet. Drying with appropriate pretreatments can extend the shelf life and availability of the product for consumption throughout the year. The present work investigates various physico-chemical and textural properties of Bitter gourd and explores the effects of different pre-treatments on drying characteristics of Bitter gourd. The textural properties were dependent on the size and were significantly ($P<0.05$) different for small, medium and large size of Bitter gourds. However, there was no such difference for physical properties such as geometric mean diameter, sphericity, surface area, aspect ratio, bulk density, true density and coefficient of friction. Various drying characteristics like moisture ratio, drying rate, moisture diffusivity, shrinkage ratio and rehydration efficiency were determined. The drying of the pre-treated Bitter gourd was mathematically modelled for three temperatures (50, 60 and 70ºC). The dried samples were analysed for biochemical quality parameters like colour, vitamin C, total phenolic compounds, 2-2 diphenyl picryl hydrazyl, and ferric antioxidant reducing power. To improve the drying quality pre-treatments like hot water blanching, microwave blanching, ethyl oleate dipping and combination of these pre-treatments were given to Bitter gourds. At 70ºC, not pre-treated samples had maximum (190min) drying time whereas the combined ethyl oleate and microwave blanched samples had minimum (100min) drying time. Thus, ethyl oleate treated microwave blanched samples significantly ($P<0.05$) reduced the drying time at all three temperatures. Drying temperature had significant ($P<0.05$) effect on moisture ratio. Increased temperature reduced the drying time of the samples. Pre-treatment and drying temperature had significant ($P<0.05$) effect on the moisture diffusivity of Bitter gourd. The moisture diffusivity was found lowest in not pre-treated samples (2.65 to 4.85 $x10^{-8} m^2/s$) and highest in ethyl oleate treated microwave blanched samples (3.86 to 7.48 $x10^{-8} m^2/s$). The moisture diffusivity was also dependent on temperature and the value increased from 3.86 to $7.48x10^{-8} m^2/s$ with increase in drying temperature from 50 to 70ºC. The activation energy was minimum (22.44 KJ/mol) for water blanched samples and was maximum (30.55 KJ/mol) for ethyl oleate treated microwave blanched samples. At 70ºC not pre-treated samples showed the highest (80.2 %) shrinkage ratio whereas ethyl oleate treated microwave blanched samples showed the lowest (52.06%) shrinkage ratio. As the drying temperature increased from 50 to 70ºC the shrinkage ratio increased significantly ($P<0.05$) from 70.3 to 80.2%. The lowest and highest rehydration ratio was found in not pre-treated and ethyl oleate treated microwave samples respectively. The rehydration ratio increased from 3.49 to 4.9% for not pre-treated samples as the drying temperature increased from 50 to 70ºC. Retention of various biochemical and nutritive parameters such as vitamin C, total phenolic compounds, 2,2, diphenyl picryl hydrazyl was highest for combined pre-treatment of ethyl oleate and microwave blanched samples. The overall drying kinetics of the pre-treated samples could be best fitted to Page Model.

Keywords**:** ***Bitter gourd; pre-treatments; drying; modelling; nutritional properties***.

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List of Symbols and Abbreviations

%	-Percentage
°C	-Degree Celsius
μg	-Micro gram
ANOVA	-Analysis of Variance
AOAC	-Association of Analytical Chemists
Df	-Degrees of freedom
EO	-Ethyl Oleate
g	-Gram
h	-Hour
ha	-Hectare
IU	-International Unit
J	-Joule
K	-Kelvin
Kcal	-Kilocalorie
Kgy	-Kilo gray
KMS	-Potassium metabisulphite
mg	-Milli gram
min	-Minutes
MS	-Mean of Square
MT	-Metric Ton
N	-Newton
NaCl	-Sodium Chloride
NHB	-National Horticulture Board
P	-Probability value
RH	-Relative Humidity
RMSE	-Root Mean Square Error
s	-Seconds
SSE	-Sum of Square Error
W	-Watt
wb	-Wet basis
ΔE	-Overall color change

Chapter 1

Introduction

1.1 Background

Fruits and vegetables, among the perishable commodities, are the most important ingredients in our diet. Due to their high nutritive value, they make a significant contribution to our nutrition. India has the second largest production of fruits and vegetables in the world next to China. National Horticulture Board (2014) has reported that the productions of fruits and vegetables in India are 82 and 162 million tonnes respectively. The overall productivity of the fruits is 11.8 tonnes per hectare and vegetables is 14.9 tonnes per hectare. Our share in the world production is about 10.1% in fruits and 14.4% in vegetables. But, the production of these perishables are comparatively lower as compared to some of the other developing and developed countries. The present status of processing and value addition is about 2.2% of the total production in India. Processing of fruits and vegetables is higher in the developed countries like USA (80%), France (70%) and Thailand (30%). Out of the total production in India about 30-40% wastage is reported because of inappropriate post-harvest practices and handling. The fruits and vegetable processing sector in India is categorised as organised (25%), unorganised (42%), and small scale Industries (33%) (Singh *et al.*, 2014).

Fruits and vegetables are highly perishable in nature due to their high water content. Even after harvesting active metabolism and ethylene production continues and, therefore, early deterioration of the product takes place. Proper preservation and processing plays an important role in extending shelf life of fruits and vegetables. This can be accomplished by several methods, including canning, blanching, freezing and dehydration. Blanching and dehydration are the most common methods.

Bitter gourd (*Momordica Charantia L.*) (Fig 1.1) is a well-known vegetable cultivated worldwide and mostly consumed in Africa, South America and South Asia (Whitaker, 1990). It belongs to the *Cucurbitaceae* family. It is commonly known as bitter melon, *karela*, *karavelli*, *balsam pear*, *pakar*, *karli*, *baramasiya*, *kakara* and *kaypa* (Jadhav, 2008). India contributes to about 31% of Bitter gourd production in the world.

The total area under this crop during 2012-13 was 78.12 thousand hectares and the production was about 883.69 thousand tonnes (NHB, 2014). It is a traditional vegetable that has been in use for centuries all across the world. Bitter gourd has also prominence in Ayurveda for treating major diseases like diabetes, cancer, digestive disorders, malaria, blood pressure and cholesterol (Budrat and Shotipruk, 2008). Bitter gourds are harvested in the month of April and May (Unal *et al*., 2013). It is also used as food supplement for vitamin, minerals, bioactive chemicals and antioxidants. It is an excellent source of various antioxidant compounds like DPPH (2, 2, diphenyl picryl hydrazyl), total phenolic compound (TPC) and ferric reducing antioxidant power (FRAP) (Budrat and Shotipruk, 2008; Myojin *et al*., 2008). It also contains other important chemical constituents such as α-Momorcharin, β- Momorcharin and glycoproteins, making it an excellent source of nutrients. It is a substantially nutrient rich vegetable having various beneficial components like vitamins, minerals, bioactive chemicals, and antioxidants (Bakare, 2010). The matured Bitter gourd is rich in vitamin C, vitamin A, β-carotene, phosphorous and iron.

Figure 1.1: Bitter gourd

Source: Internet

In addition to its nutritional properties, it is also known for its medicinal properties such as anti-diabetic, anti-cancer, anti-tumor (Budrat and Shotipruk, 2008). As the name indicates, Bitter gourd is the most bitter vegetable among all the vegetables. The bitterness of the vegetable is attributed to two principal components, momordicin and charantin whose structure in shown in Fig 1.2 and 1.3 (Kumar, 2010)

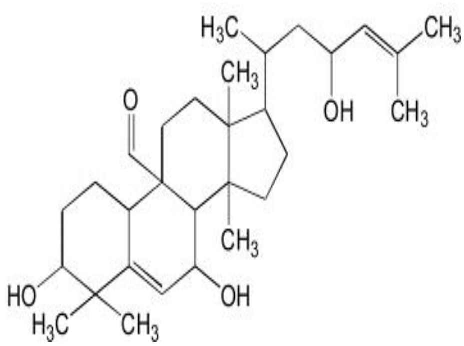

Figure 1.2: Structure of momordicin

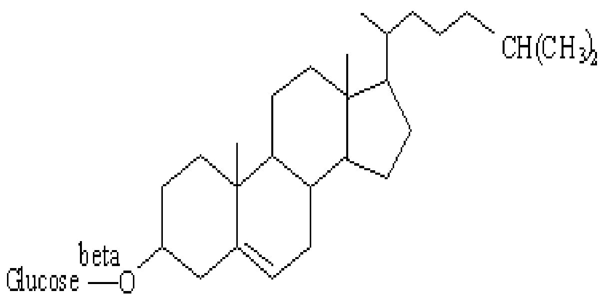

Figure 1.3: Structure of charantin

India, China, Philippines, Taiwan and Vietnam are the largest producers of Bitter gourd in the world. India produced about 971 thousand tonnes of Bitter gourds from the major states of Andhra Pradesh, Odisha, Bihar, and Chhattisgarh (Ministry of Agriculture, 2014). Canned Bitter gourd, chips, pickle, juice and powder are also available in the market.

Though the production is high, the average rate of post-harvest loss of Bitter gourd per annum is about 25% of the total production (FAO, 2012). The shelf life of this vegetable is less (3-4 days) at room temperature. It is due to its high water content and rapid ethylene production. Proper pre-treatments and drying methods are needed to extend the shelf life and to improve the availability of Bitter gourd throughout the year.

Pre-treatment is an important unit operation carried out before drying in order to overcome the problem of moisture removal. It helps to transfer the moisture quickly from the interior by dissociating the waxy substance and forms cracks at the surface of fruits and vegetables. The pre-treatments can be classified into four types, namely, thermal (hot water blanching, steam blanching), mechanical (abrasion, peeling, cutting), chemical (acidic, alkaline, oleate esters) and electro-technologies (pulsed electric field, ultrasound and ohmic). The other advantages of pre-treatments include destruction of enzymes and surface microorganism, removal of entrapped air and acceleration of drying rate.

Blanching is a pre-treatment method adopted for most of the vegetables. The heating is done either by hot water, steam or microwave. Product size, structure, maturity of the vegetable influences the blanching process and quality. Blanching of vegetables help in inactivation of enzymes, removal of entrapped air, softening of tissues and reduction of microorganisms. This process also helps in eliminating browning, shrinkage and off flavour in the vegetables during drying.

Various chemical treatments are used to limit oxidation of various constituents of fruits and vegetables. Ethyl oleate and methyl oleate are the two chemicals that are mostly used for pre-treatment of vegetables. Apart from these, Potassium Metabisulfite (KMS) and Sodium Chloride (NaCl) are also used. Ethyl oleate ($C_{20}H_{38}O_2$) is one of the long-chain fatty acid ethyl esters which is formed by the condensation of carboxy group of oleic acid and hydroxy group of ethanol. It is an insoluble, colourless oil which is used for drug preparation in pharmaceuticals. Ethyl oleate is approved by Food and Drug Administration (FDA, USA) for consumption under the category "Food Additives Permitted for Direct Addition to Food for Human Consumption".

Drying is used to reduce the moisture content of food and thereby preserve the high or moderate moisture food. It can be carried out using thermal, as well as non-thermal technologies depending on the food. In addition to the moisture removal, drying also helps in breaking the suface coating and cell wall, thus, releasing the phenolic components from the food matrix.

Bitter gourd is highly nutritive and energetic. It has many healing properties and is recommended for major diseases like bloodstream, rheumatism, diabetes and asthma. But the bitterness within this vegetable is not liked by many. So, value addition of Bitter gourd by preparing beverages is thought to increase its palatability and acceptability in conjunction with taste and flavour. The processing of Bitter gourd increases the availability of the product throughout the year in the form of juice, natural powder, chips, and dried rings. The juice is usually stored for a longer period with the help of organic or chemical preservatives. The Bitter gourd chips eliminate the bitterness and increase the marketing value. Bitter gourd powder is commercially available for direct intake. Bitter gourd capsules are also available commercially and is recommended for managing the sugar levels and is included in the diet plan of diabetics.

1.2 Problem statement, Knowledge Gap and Justification

Though the production of Bitter gourd is high, the post-harvest loss of Bitter gourd was estimated to be about 25% (FAO, 2012). There is a need of advanced technology for reducing post-harvest losses of Bitter gourd. The processing and value addition of Bitter gourd is fewer. It is due to improper handling, storage, pre-treatment and drying. The shelflife of Bitter gourd is less. In an ambient condition, it can be stored upto 3-4 days and prolonged to 14-21 days storing at refrigerated condition. Pre-treatments like hot water blanching leads to loss in vitamins, nutrients and other biochemical qualities of Bitter gourd. The processing (blanching) time was higher. Drying without proper pre-treatment develops rubbery texture, browning, shrinkage and degradation in the sensory and nutritional qualities of the product. There is no substantial report on the physical, chemical and textural properties of Bitter gourd. The literature explained various pre-treatment methods adopted for fruits and vegetables. These pre-treatments have resulted in nutrition and quality loss. Researchers have explored the application of hot water blanching, microwave blanching and ethyl oleate (EO) pretreatment in processing and value-addition of many other vegetables. The microwave blanching retains the nutrients and vitamins. EO improves drying rate and decreases the drying time.

The present work explores the effects of ethyl oleate and blanching methods (Hot water and Microwave) on the drying characteristics of Bitter gourd and compares the quality parameters of dried and fresh Bitter gourd.

1.3 Objective

The overall objective is to improve the post-harvest processing and value addition of Bitter gourd. To meet the overall objectives, the following objectives were investigated.

- ✓ To determine the physico-chemical and textural properties of Bitter gourd
- ✓ To investigate the effect of pre-treatments on drying characteristics of Bitter gourd
- ✓ To perform a mathematical model of dried Bitter gourd
- ✓ To analyse the quality attributes of dried Bitter gourd

1.4 Organization of thesis

The thesis is divided into five chapters excluding front pages, references, dissemination and appendices.

Chapter 1 gives a general introduction to the thesis, background of the work, problems being faced in Bitter gourd processing and the objectives of the research.

Chapter 2 reviews available literature on current scenario of Bitter gourd production and processing, various pre-treatments and drying methods available and about mathematical modelling of the process.

Chapter 3 describes the materials and methods adopted for the whole work. The overall experimental plan of the research is described in this chapter. It explains procurement of raw materials, sample preparation, standard methods followed and various equipment and machines used in the work.

Chapter 4 includes the results of various experiments planned in the previous chapter and discusses it with reference to the reported works. Experimental data have been statistically presented and analysed in the form of tables and figures.

Chapter 5 presents the overall summary and conclusions from the present work which would help researchers in design and development of appropriate technology for processing and value addition of Bitter gourd. It also suggests future scope of the present research work.

Chapter 2

Review of Literature

2.1 Bitter gourd

Bitter gourd is widely cultivated throughout the world. It is generally known as bitter melon and belongs to *Cucurbitaceae* family. Seven varieties of Bitter gourd are available in India, out of reported eight hundred varieties (Hamissou *et al.*, 2013). The common varieties cultivated in India are *Momordica charantia, M. balasmina, M. dioca and M. chochinchinesis*. It is an herbaceous plant which can be used both for food and medicine (Grover and Yadav., 2004).

M. charantia is monoecious vine type plant. The Bitter gourd of this variety comes with varied size and shape. Bitter gourd is slender, with long stalked leaves. Solitary male and female flowers born in the leaf axils. The common Bitter gourds are 20 to 30 cm long, oblong with bluntly tapering ends and pale green in colour, with a gently undulating warty surface. It is a popular vegetable in South Asian and American countries. It is often prepared with potatoes as *sabji* and served with yogurt on the side to offset the bitterness (Behera *et al*., 2010)

Bitter gourd is regarded as one of the world's major vegetables and has great economic importance. It is also a promising vegetable with nutritional quality that can help millions in the developing world who suffer from metabolic disorders such as type-2 diabetes (Raman and Lau, 1996). Due to its nutritional and medicinal value, Bitter gourd is considered as an all-purpose crop. Bitter gourd has been used in various Asian traditional medicine systems for a long time (Beloin *et al*., 2005). Bitter gourd can be helpful to people with sluggish digestion, dyspepsia, and constipation, excess consumption may, sometimes, lead to heartburn and acidity. Bitter gourd is also a demulcent and mild inflammation modulator. However, these negative effects have never been reported (Rao *et al*., 1991).

Bitter gourd plays an important role in reproductive health as an abortifacient, birth control agent, or to treat painful menstruation and to facilitate childbirth (Leung *et al*., 2009). The antiviral activity of Bitter gourd has already been reported in literature (Anani *et al*., 2000; Hudson *et al*., 2000).

Though, it has been claimed that bitterness of the Bitter gourd comes from quinine, there is no evidence to support this claim. Bitter gourd has also been used traditionally for treating malaria in many south Asian and American countries. Laboratory studies have confirmed that various species of bitter melon have anti-malarial properties. However, results of human trials have not been published (Tan *et al.*, 2008).

Bitter gourd has a number of health benefits like antibacterial, anthelmintic, aperitive, anti-leukemic, antibiotic, antidiabetic, anti-inflammatory, anti-mycobacterial, antioxidant, aphrodisiac, antimicrobial, anti-mutagenic, anti-tumor, anti-ulcer, hypocholesterolemic, antiviral, stomachic, hormonal, tonic, astringent, laxative carminative, hypoglycemic cytostatic, purgative, depurative, hypertensive, hypotriglyceridemic, immunostimulant, lactagogue, and styptic effects (Saeed *et al*., 2012).

The main elements of Bitter gourd which are responsible for medicinal properties are alkaloid triterpene, lipid, proteid (a type of protein), steroid, phenolic compounds, and many other inorganic compounds. Charantin, an important component in Bitter gourd, is responsible for its anti-diabetic activity. The phenolic compounds from Bitter gourd extract exhibit antioxidant activities (Budrat and Shotipruk, 2008).

Bitter gourd is famous for its medicinal properties due to the presence of both enzymatic and non-enzymatic antioxidants (hydrogen peroxide enzymes, phenolic compounds, vitamins and gallic acid) (Kubola and Siriamornpun, 2008). The antioxidant activity varies with the variety (Hamissou *et al*., 2013). These antioxidant activities could be determined based on the inhibition of free radical diphenyl picryl hydrazyl (DPPH) and ferric reducing antioxidant power (FRAP). Bitter gourd has 82% of inhibition effect of DPPH and β-glucosidase than Zucchini. The vegetable extract had the highest antioxidant activity than that of leaves and stem (Dasgupta and De, 2007). *Momordica dioca* possesses highest DPPH and TPC (Scartezzini and Speroni, 2000; Wu and Ng, 2008).

2.1.1 Nutrient profile

Over the years, many scientists have reviewed the nutrient contents of Bitter gourd. As per United States of Nutrient Database (USDA), the important nutrient components of fresh Bitter gourd per 100g are listed in Table 2.1. Bitter gourd is highly rich in vitamin C and lower in fat and cholesterol. This contributes to its health healing properties.

The fresh Bitter gourds are rich in biochemical components. The active component responsible for bitterness is charantin. It consists of a mixture of beta-sitosterol-beta-D-glucoside and 5, 25, stigmadien-3-beta-ol glycoside (Cantwell *et al.,* 1996). Bitter gourd contains other important components such as curcurbitins, cryptoxanthin, curcurbitacins, momorcharasides cycloartenols, charine, diosgenin, elaeostearic acids, cucurbitanes, erythrodiol, goyaglycosides, gypsogenin, galacturonic acids, momordolo guanylate cyclase inhibitors, momordenol gentisic acid, goyasaponins, lauric acid hydroxytryptamines, polypeptides, karounidiols, lanosterol, myristic acid, linoleic acid, linolenic acid, rosmarinic acid momorcharins, momordicillin, momordicinin, momordicosides, trypsin inhibitors petroselinic acid, stigmastero, rubixanthin, taraxerol (Sharma *et al.*, 2014)

Table 2.1: Nutrient values of fresh Bitter gourd

Nutrients	**Values**
Energy	17 Kcal
Potassium	296 mg
Vitamin C	84 mg
Vitamin A	471 IU
Calcium	19 mg
Sodium	5 mg
Carbohydrates	3.70 g
Dietary Fibre	2.80 g
Protein	1.00 g
Total Fat	0.17 g
Carotene B	190 µg
Carotene C	185 µg
Cholesterol	0.0 g
Carotene B	190 µg
Potassium	296 mg
Iron	0.43 mg

Source: USDA, 2014

2.1.2 Production status

The worldwide production of Bitter gourd is shown in Fig 2.1. Bitter gourds are cultivated in all parts of India. They are harvested at the end of summer and beginning of rainy season (Potawale *et al.,* 2008). Bitter gourd differs in shape, size and maturity, depending on region. Indian variety Bitter gourd has narrow shape, pointed ends with triangular teeth and sharp edges. Generally, the vegetable is 5-25 cm long. It is hollow in cross section having tender skin, thin layer of flesh, white seeds and pith. It is used for cooking when it is green and matured. On ripening, seeds become red and fruit becomes mushy, yellow and splitted (Sharma *et al.*, 2014). The total production and area under Bitter gourd cultivation in India are given in Table 2.2

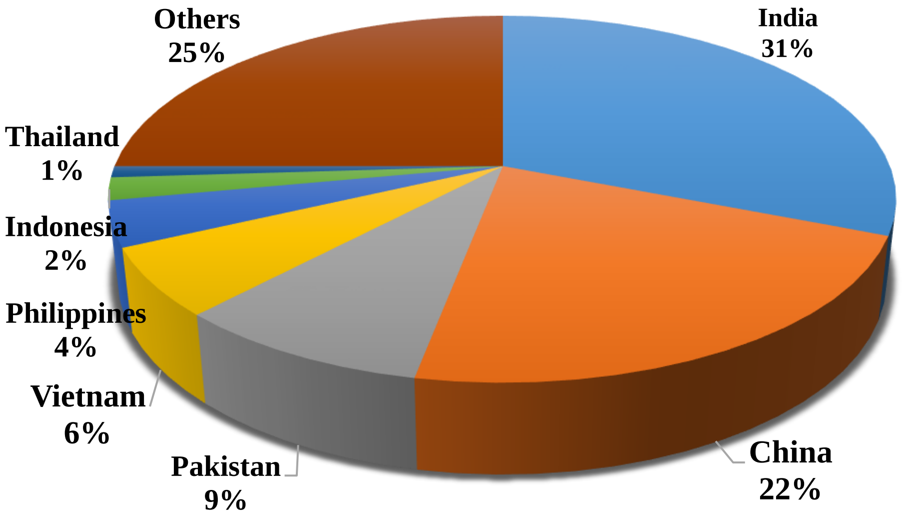

Figure 2.1: International status of Bitter gourd production (2012-2013)

Source: Ministry of Agriculture, 2014

Table 2.2: National status of Bitter gourd production (2013-2014)

States	**Area ('000ha)**	**Production ('000MT)**
Andhra Pradesh	21.74	326.1
Assam	5.22	49.51
Bihar	10.09	78.14
Chhattisgarh	7.26	94.93
Karnataka	3.10	28.60
Madhya Pradesh	5.28	53.78
Mizoram	3.90	20.40
Odisha	11.49	112.29
Punjab	2.04	30.51
Uttar Pradesh	1.51	26.27
Total (including others)	78.12	883.69

Source: National Horticulture Board, 2014

2.1.3 Harvesting and Storage

Though the production is high, the average rate of post-harvest loss of Bitter gourd is about 25% of the total production (FAOSTAT, 2012). It is mainly due to the perishable nature of the vegetable. It is seasonal and available only in the harvesting seasons. The Bitter gourds are harvested after 90 days of planting. The vegetable is harvested when the outer colour is dark green and the seeds are soft and creamy (Vujovic *et al*. 2000). The flesh should be juicy and thick (Lim 1998). To avoid loss due to quick ripening, Bitter gourds are harvested every 2-3 days when it is matured (Desai and Musmade 1998). Bitterness increases with time due to build-up of the alkaloid momordicine. It loses bitterness during ripening (Cantwell *et al*. 1996). Harvesting can be done manually using clean sharp knife before it ripens.

Bitter gourd is one among the climacteric vegetable which continues to ripen rapidly due to high ethylene production rate even after harvesting. The ethylene can be controlled by storing at an optimized temperature of 5-7ºC (Gosbee and Lim, 2000). Bitter gourds stored below 2ºC develops chilling injury. Storage at higher temperature favours ripening. The proper storage can contribute to reduced physiological losses (Morgan and Midmore, 2002).

Bitter gourd is perishable in nature due to its high moisture content (>90 %wb). It has a shelf-life of one week in ambient condition. The shelf-life can be prolonged to 10-14 days when it is refrigerated at 5-7ºC (Moss, 2002). The continuous refrigerated storage gives the undesirable changes in the vegetable such as chilling injury, fruit splitting, colour degradation, surface degradation, resetting and internal tissue break down. In order to avoid rapid refrigeration, Bitter gourds are packed in poly ethylene wrapper and stored at 7ºC. Proper packaging improves the nutritional quality and extends shelf-life to at least twenty one days (Mohammed and Wickham, 1993). Modified atmosphere packaging (3% O_2 and 5% CO_2) of Bitter gourd retains chlorophyll, ascorbic acid, titrable acidity with minimal physiological loss (Preetha *et al.*, 2015).

2.1.4 Processing and Value addition

Bitter gourd is rich in vitamins, nutrients and antioxidant properties but deteriorates quickly. Different processing methods and value addition are required to extend its shelflife (Kidmose and Martens, 1999). Various pre-treatments and drying methods were reported in literatures. Bitter gourd dried without any pretreatment increases browning and decreases the product quality (Dasgupta and De, 2007). So, pretreatments like blanching (wet and dry), sulphitation, ascorbic acid, sodium chloride (NaCl) and potassium meta bisulphite (KMS) have been used to preserve the quality of Bitter gourd after drying (De Corcuera *et al.,* 2004).

Sagar (2013) reported that Bitter gourd blanched for three minutes and soaked in 0.2% KMS for fifteen minutes retained the colour and texture. The similar results were reported by Siva Kumar *et al.* (1991) when Bitter gourds blanched for three minutes with addition of 2% NaCl. Blanching of four minutes and soaking in 0.49% of KMS for the same time retained the maximum chlorophyll and hardness as fresh (Jadhav *et al.,* 2010). The thickness of sliced Bitter gourd is the major factor during blanching. Bitter gourd sliced for 0.5 cm and blanched for three mins and subsequently soaked in 0.2 % KMS and 2% NaCl solution for ten mins retained the highest chlorophyll, ascorbic acid and rehydration ratio with reduced titrable acidity and non-enzymatic browning (Dhotre *et al.,* 2012).

In addition to its nutritional properties, antioxidant properties are also important quality attributes in Bitter gourd. Blanching affects the antioxidant properties of Bitter gourd. Many researchers reported the positive effect of blanching on scavenging activity of Bitter gourd. Aminah and Permatasari (2013) reported that deep frying at 100ºC for ten mins and microwaving at 900 W for ten mins resulted in highest Total Phenolic Compounds (TPC) and 2,2, Diphenyl Picryl Hydrazyl (DPPH) scavenging activity in Bitter gourd. Blanching increased the activity of DPPH but decreased the ascorbic content after 90 days of frozen storage (Myojin *et al.*,2008).

Antioxidant properties varies with varieties. Choo *et al.* (2014) compared effect of blanching methods on antioxidant properties of two varieties of Bitter gourd namely *Momordica charantia* var. minima and *M. charantia* var. maxima. *M. charantia* var. maxima had highest the ascorbic content, TPC and DPPH scavenging activity after blanching.

Blanching highly improved the quality characteristics of Bitter gourd after drying. However, leaching loss is the major disadvantage in hot water blanching. Khatun *et al.* (2012) observed the loss of nutrients and vitamins in vegetables after blanching due to degradation of heat sensitive vitamins. To overcome this problem, Kulkarni *et al.* (2005) reported the importance of sulphitation. The pre-treatment of sulphitation (0.2% KMS with 1% sodium sulphite solution) for ten mins at room temperature preserved the color and maintained a better texture in Bitter gourd without leaching.

Patil (2014) reported that, microwave blanching of Bitter gourd at a power density of 4 - 5 W/g for 1-2 mins retained the maximum chlorophyll and other proximate composition with minimal leaching. A non-thermal treatment of gamma irradiation (0.25 Kgy) increased the phenolic and flavonoid content but decreased the ascorbic content of Bitter gourd. The blanching process should ensure complete inactivation of enzymes along with minimal negative effects in all aspects (Volden *et al.*, 2008)

2.2 Pre-treatments

Pre-treatments plays an important role in permeabilisation, enzyme inactivation, oxidation, and accelerating the drying rate in many fruits and vegetables. Permeabilisation is the process of removing a protective wax layer in fruits and vegetable. This wax layer interrupts the moisture removal during drying (Quenzer and Burns, 1981). Oxidation is the second most important cause of food deterioration in fruits and vegetables. When cut fruits and vegetables are exposed to air, oxidation occurs due to enzymatic browning. The oxidoreductases enzymes (peroxidase and polyphenol oxidase) are responsible for these reaction. The rapid formation of browning occurs in many fruits and vegetables during drying due to absence of proper pre-treatments.

To overcome the above problem, various pre-treatments were reported. Pre-treatments are classified as physical, chemical and mechanical processes. Physical pre-treatments include water blanching, steam blanching, microwave blanching. The dipping of vegetables in an ethyl oleate, chelating agents, antioxidant agents, acidifying agents and firmness agents are some of the chemical pre-treatments. Mechanical pre-treatments include perforation, abrasion and vacuum impregnation. High hydrostatic pressure, pulsed electric field, infrared, gamma irradiation and ultraviolet are some of the non-thermal methods to replace thermal processing methods (Ioannou, 2013). All these pretreatments were used to extend the shelflife of fruits and vegetables. However, thermal processing methods like hot water blanching and microwave blanching are widely applied in various fruits and vegetables to prevent oxidation and enzyme activation.

2.2.1 Hot water blanching

The thermal pre-treatments are categorised as blanching, pasteurisation, sterilisation and cooking. Hot water blanching is one of the common thermal pre-treatments of fruits and vegetables. It is widely implemented prior to freezing, canning and drying. g. All thermal processing methods varies with temperature and food material (De Corcuera *et al.*, 2004).

Water blanching is the uniform heating process of exposing vegetables in a temperature range of 70 to 100ºC for few minutes (Arroqui *et al.,* 2002). The process can be either high temperature short time (HTST) or low temperature long time (LTLT) depends on the food products. The main objective of blanching is to inactivate the enzymes, remove an entrapped air, destruction of microorganisms and accelerate the drying rate by softening the tissues (De Corcuera *et al.*, 2004).

Hot water blanching has been used widely for wax removal from various fruits and vegetables like Bitter gourd (Choo *et al*., 2014), pineapple (Agarry *et al*., 2013), ball pepper (Akintunde *et al*., 2011), carrot (Kidmose and Martens 1999) and potato (Arroqui *et al*., 2001). Vegetables suffers to undesirable changes in texture, flavour, aroma and colour due to oxidation. In order to prevent oxidation due to browning, blanching was experimented on fruits and vegetables (Barrett and Theerakulkait, 1995). The complete enzyme inactivation of fruits and vegetables was observed in water blanching. Other than inactivation of enzymes, blanching has other major advantages like removing tissue gases, stabilize the colour of the products (Pilnik and Voragen, 1991). Cold blanching and hot blanching are the two blanching methods are approved in industries. Cold blanching is a method of dipping fruits and vegetables in a salt solution to retain the colour, texture and remove the excess water. Hot blanching is the method of dipping foods in hot water maintained at a temperature below 100ºC for few minutes (Lund, 1988). The enzyme responsible for browning are peroxidase, polyphenol oxidase and lipoxygenase. Blanching condition is optimized to inactivate the most heat resistant enzyme i.e. peroxidase (Rice-Evans and Miller, 1996). The adequacy of blanching was determined by its enzyme inactivation regardless of blanching condition.

Green leafy vegetables are studied for its chlorophyll and other antioxidant properties. Heberlein *et al.* (1950) reported blanching of one minute retained maximum ascorbic acid and 10 % thiamine loss in sweet peas. They also reported that thiamine does not undergo any oxidative change due to water blanching.

Blanching had better effects in vegetables especially green leafy vegetables such as asparagus, amaranthus (Oboh, 2005), fenugreek leaves (Sablani, 2006) and Brussel (Olivera *et al.*, 2008). Blanching at 80 to 90ºC for 2-3 minutes increased the ascorbic acid, beta carotene, chlorophyll, flavonoid compounds, texture, phenolic compounds and other sensory qualities of vegetables (Negi and Roy, 2000; Song *et al.,* 2003).

The maximum retention of ascorbic acid, chlorophyll, flavonoid compounds, TPC were reported in Rambutan peel (Nurhuda *et al.,* 2013), bell pepper (Akintunde *et al.*, 2011) after blanching for two to three minutes. Paul *et al.* (2012) investigated the increased retention of the ascorbic content as well as, reduced level of phytate and oxalate (anti-nutrients) in spinach and bathua blanched for 10 minutes. High temperature short time blanching is optimised for enzyme inactivation and nutrient retention in green leafy vegetables.

Blanching significantly affected the drying characteristics of many fruits and vegetables like banana (Taiwo and Adeyemi, 2009), bell pepper (Akintunde *et al.*, 2011), quince pomace (Brown *et al.,* 2013) and yam (Oyewole and Olaoye, 2012). The blanched food increased the drying rate at the initial stage and gradually decreased.

Though hot water blanching has numerous benefits, Arroqui *et al.* (2002) and Lo *et al.* (2002) observed the serious problem of leaching in potato and carrot after water blanching. The prolonged hot water blanching at high temperature leads to loss of water soluble vitamins and heat sensitive vitamins. But, Schweiggert *et al.* (2005) suggested that, if proper temperature and time maintained during blanching, the sensory and other quality loss can be minimised.

2.2.2 Microwave blanching

However, water blanching methods are commercialised, the major problems associated with this process are leaching, energy consumption and quality deterioration. To prevent this problem many researchers reviewed about the application of electromagnetic waves in food processing. In order to minimize the leaching, microwave heating is applied as a pre-treatment to retain the nutrients and vitamins in vegetables. The effect of microwaving and microwave assisted hot water blanching were studied on various fruits and vegetables. Microwave blanching is an alternative processing of conventional blanching as it reduces the energy consumption and waste effluents by 50% (Patricia *et al.,* 2011).The application of microwave in blanching retained maximum nutrients and other vitamins than water and steam blanching.

The term microwave heating refers to the conversion of electromagnetic radiation to heat in the frequency range of 300 MHz–300 GHz (Dorantes-Alvarez *et al.,* 2000). The microwave blanching has four important mechanisms such as bound water polarization, Maxwell-Wagner polarization, free water polarization and ionic conductivity. The main principle behind microwave blanching is that, the dipolar interaction between water and food materials. When microwaves are generated from the magnetron, it penetrates into the sample where the polar molecule align themselves with the applied electric field. Due to the friction and oscillating alignment of molecules, heat generates inside the product. The rapid generation of internal energy creates pressure and increases the evaporation rate of water (Ohlsson, 2000) (Alibas, 2007). The rapid increase in temperature inactivates enzymes in short time with controllable heat deposition. This makes microwave blanching more attractive.

It saves energy, speeds up the process and retains the quality. Microwave blanching is often combined with other processing methods to reduce the disadvantage of non-uniform temperature distribution and inappropriate enzyme inactivation (Tang *et al*. 2002).

The first microwave blanching (3000 MHz) was reported on vegetables (Proctor and Goldblith, 1948). They found the higher retention of nutrients and less leaching loss than conventional blanching. The effect of pulsed microwave blanching on spinach, ball pepper and carrot was studied by Ramesh *et al*. (2002). The microwave blanching at 900 W retained the maximum amount of ascorbic acid and increased inactivation rate of peroxidase than conventional blanching. The product quantity, size, shape, maturity affects the blanching process. Blanching conditions are varied depending on power density, container location inside oven.

In order to compare the effect of hot water blanching and microwave blanching, Osinboyejo *et al.* (2003) compared the retention of vitamins after blanching. They reported that microwave blanching retained the maximum Vitamin B and C by steam and water blanching in vegetables. Lane and Abdel-Ghany (1985) reported the leaching loss of water blanching, steam blanching and microwave blanching was 39%, 38% and 35% respectively. Various treatments such as blanching, boiling and microwave cooking affects the antioxidant properties.

In addition to nutrient retention, the rapid inactivation of enzyme is being observed in microwave blanching. It inactivated the enzyme in sweet potato very rapidly along with the highest retention of anthocyanin and higher drying rate (Liu *et al,* 2015). The same results were found in beetroot and carrot when microwave blanched for 3 W/g against conventional blanching (Math *et al.*, 2014).

Microwave blanching can be a reliable for food processing than conventional blanching. It reduces 50% of the energy consumption. It also increases the nutrient properties and inactivates the enzyme at a higher rate (Patricia *et al.*, 2011). Spinach, green beans and sweet pepper found to have elevated levels of TPC at 10W/g for 1 min (Turkmen *et al.*, 2005); asparagus and broccoli observed to have increased level of ascorbic content at 700W (Brewer and Begum, 2003); banana and plantain was observed to have increased level of total sugars, total soluble acids, tannin and flavour at 1200 W (Premakumar and Khurdiya, 2002).

Bitter gourd which is microwave treated and dried at 40ºC resulted in higher DPPH and FRAP activity than conventional water blanching (Aminah and Permatasari, 2013). Researchers reported that microwave blanching softens the tissues thus improves the drying rate and also retains the nutrients due to minimal leaching. The effect of microwave blanching at 100W/g on drying characteristics of tomato were studied. The microwave blanching greatly increased the drying rate than hot water blanching at 90ºC (Ando *et al.,* 2010). Abano and Amoah (2015) demonstrated that microwave pre-treatment before drying of yam increased the heat and mass transfer that increased the drying rate and decreased the drying time but resulted in reduced ascorbic content. The heat penetration between convection and microwave heating is shown in Fig 2.2.

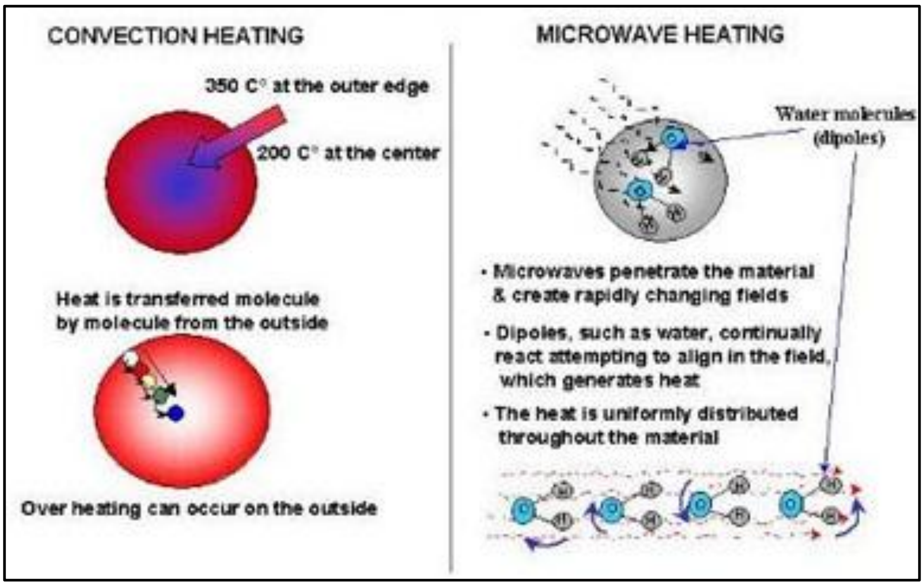

Figure 2.2: Heat penetration between convection and microwave heating

2.2.3 Ethyl Oleate dipping

However, water blanching and microwave blanching enhanced the quality and drying characteristics, shrinkage is the major problem. Due to high temperature processing, the product shrinks more. The increase in temperature releases the pressure and creates stress in the structure of tissue. This sudden heat release modifies the structure and contradicts the structure of the food material (Biekman *et al.,* 1996). There are so many literatures available on application of hot water blanching, steam blanching and microwave blanching. Only few researchers reviewed about the application of ethyl oleate (EO) on drying characteristics of vegetables.

The chemical permeabilisation by ethyl oleate dipping have been studied for various fruits. The effect of EO on drying characteristics of grapes (Pangavhane *et al*. 1999), apricot (Doymaz 2004), ginger (Deshmukh *et al*. 2013), red pepper (Doymaz and Pala 2002) and tomato (Doymaz 2007a) were reported. Ethyl oleate reduced the drying time more effectively. The reaction of ethyl oleate with food is shown in Fig 2.3. Ethyl oleate acts as a surfactants and wetting agent. It increases the evaporation rate and drying rate by faster diffusion. And also ethyl oleate dissociates the wax cuticle layer around the food and creates pores in the tissues for faster moisture removal during drying (Heldman *et al.,* 2006).

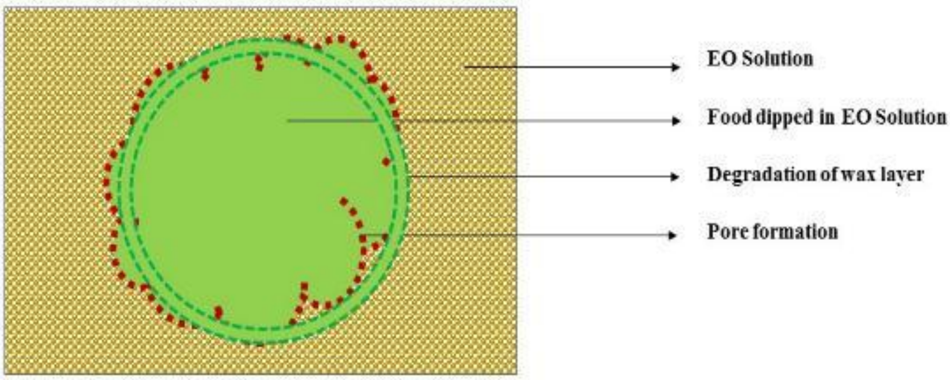

Figure 2.3: Reaction of EO with food

The first study of EO was reported by Tulasidas *et al.* (1996). They reported that pre-treatment 3% EO and 0.5% Sodium hydroxide (NaOH) and subsequently dried in microwave resulted in better dehydrated product of grapes. Followed by them Doymaz and Pala (2002) reported that 2% EO and 5% K_2CO_3 (potassium carbonate) increased the drying characteristics of red pepper. Along with drying characteristics, colour retention was also higher.

The effect of EO were reported on apricots (Doymaz, 2004), mulberries (Doymaz and Pala, 2003), sour cherry (Doymaz, 2007b) and tomato (Doymaz, 2007a). They reported that, the waxy layer of these fruits was dissociated by EO solution and increased the evaporation rate and drying rate during drying.

The application of EO is being studied in many fruits and vegetables. EO greatly affects the drying characteristics. Deshmukh *et al.* (2013) reported that dipping of ginger in 2% EO and 5% K_2CO_3 at room temperature increased the drying characteristics and the effective diffusivity increased from 4.43 $x10^{-10}$ to $1.89x10^{-9}$ m^2/s.

EO highly affected the rheological and sensory properties. Davoodi and Nikkhah (2014) reported sensory properties of Mulberry after 150 days of storage. Dipping of Mulberry in 2% EO and 0.5 % KMS, packed in poly styrene pouches and stored under 20ºC gave the highest acceptability. And also EO significantly increased the antioxidant properties like DPPH, ascorbic acid, TPC and β-Carotene in strawberry fruit (Orak *et al.,* 2011). The combined effect of oil dipping and blanching was studied by Akintunde *et al.*, (2011). They reported that dipping of ball pepper in palm oil and water in the ratio of 1:20 (v/v) in addition of 0.1g of butylated hydroxyl anisole (BHA) and blanched at 95ºC increased the drying rate than hot water blanching.

2.3 Drying characteristics and Modelling

2.3.1 Drying rate

Drying is one of the economic and effective way of extending the shelflife of foods. Sun drying of fruits and vegetables is one of the oldest method of drying. The main disadvantages of this method are contamination, quality deterioration and seasonal dependent. In order to overcome this problem, solar dryer was developed. Solar dryers are used to dehydrate the foods using natural radiation of sun in a protective way. It reduced the contamination by insects, animals and other external damages. However, being a commercialised method, prolonged drying time in solar drying leads to deteriorate the nutritional and sensory qualities of foods.

The mechanical hot air drying was developed for rapid drying of foods. The fresh air is heated and passed to the high moisture foods for faster moisture removal. Mechanical or hot air drying is an alternate method of drying to overcome the above problem.

Drying takes place by convection (direct dryers), conduction (contact or indirect dryers), radiation (microwave or radio frequency) depends on the foods (Mujumdar and Devahastin, 2000). Drying rate is one of the important drying characteristics of food materials. The typical drying curve of all foods are shown in Fig.2.4

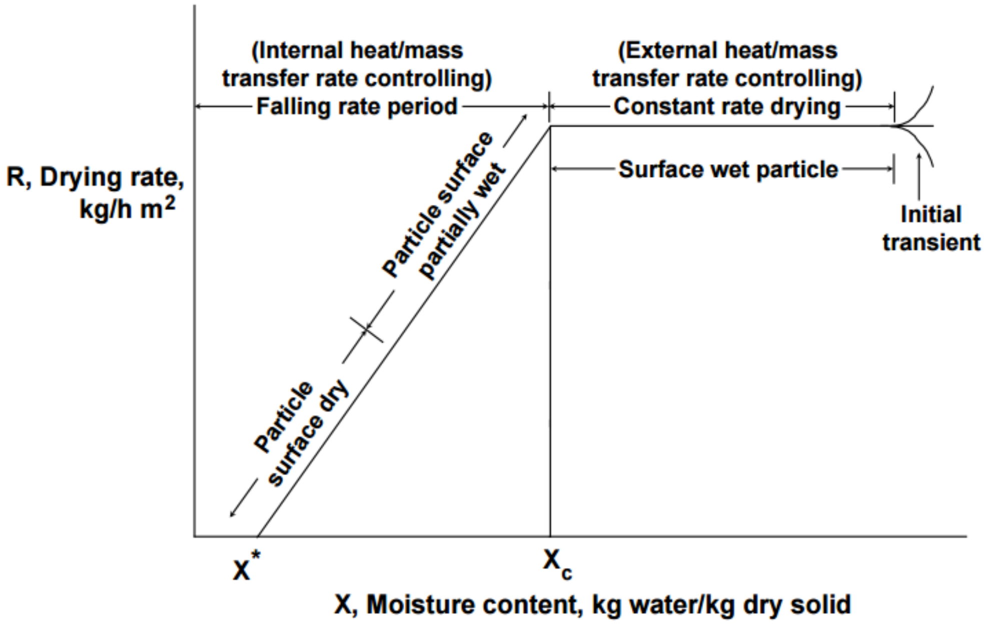

Figure 2.4: Drying rate curve

The moisture in foods are classified into free, bound and unbound moisture. These moistures are removed by convective drying process. The drying process can be explained as constant rate, first falling and second falling rate period. In the constant rate period, the overall drying rate is determined by the heat and mass transfer through external such as the temperature, gas velocity, total pressure and partial pressure of the vapour. The moist surface behaves like a free water surface. This period continues until critical moisture content reaches. In the falling rate period, the rates of internal heat and mass transfer determine the drying rate. Drying rate decreases gradually and moisture evaporates from the material surface to the air (external diffusion) in the first falling rate period. In the second falling rate period, the inner moisture evaporates and reaches the equilibrium moisture content (internal diffusion). The moisture movement in drying process is classified into capillary flow, liquid diffusion, surface diffusion, vapour diffusion, thermal diffusion and hydrodynamic flow. The Concentration of moisture can be expressed by relative mass fraction of the liquid (Sahay and Singh, 1996)

$$X_A = M_A / M_C,$$

where, M_A is the mass of water and M_C is the mass of dry material.

2.3.2 Mathematical Modelling

To understand a simultaneous heat and moisture transfer during drying, the internal structure of foods has to be modelled. The internal structure may be porous or non-porous. Depending on this, the transfer of moisture differs. For this purpose, the mathematical modelling was done for various fruits and vegetables.

Modelling of the drying processes can be generally characterized into two different approaches: physical based modelling and empirical modelling. Physical based modelling is mathematically formulated from the basic physical principles of the drying process. The empirical models predict the average moisture content as a function of drying time. The existing models of thermal processes in food can be broadly divided into four groups. The first group depends on heat and mass transfer that includes all lumped models and does not consider any physics. These models are entirely empirical models which is suitable for only specific processing and specific product.

To predict modelling for all foods, the second group was discovered to assume both energy and diffusion moisture transfer. The third group compared the simple diffusion models and assumes a sharp boundary conditions for both dry and wet regions. Later, the fourth model was developed to analyse the tissue culture, cellular structure of material based on chemical and physical process which restricts the isothermal drying conditions. Therefore, the modelling helps to analyse the drying characteristics of various fruits and vegetables.

Over two hundred references of mathematical models of drying of porous foods were reported by Waananen *et al*. (1993). These models are helpful to describe drying processes to optimise the engineering design, development and analysis. A mathematical description of the model is mainly based on the physical mechanisms of internal heat and mass transfer, structure and thermodynamic assumptions.

2.3.3 Effect of Drying Temperature on Drying Kinetics

Drying was studied in a convective tray drier at drying temperature of 60ºC using rectangle-shaped apple slices. The influence of air temperature and velocity was studied on heat transfer, effective diffusivity, rehydration ratio of dried apple slices.

It was found that increased airflow velocity increased the heat transfer coefficient and effective diffusion coefficient. 72 % of rehydration efficiency was reported after convective drying. The experimental data were well fitted into an exponential mathematical model. Two well-defined falling rate periods and short constant rate period at lower air velocities was observed (Velic *et al*., 2004).

Ayyappan and Mayilsamy (2010) reported the better dehydrated Bitter gourd dried in natural convection solar tunnel dryer. It reduced 50% of the drying time from the traditional solar dryer. Jadhav *et al.* (2010) reported that the Bitter gourd blanched for 0.49% KMS and dried in the solar cabinet dryer at 38-62ºC and 45-55% RH retained the highest chlorophyll content. Umayal Sundari *et al.* (2013) reported that Bitter gourd dried in solar dryer with an evacuated tubing air collector, blower and chimney reduced the moisture from 91% to 6.25% in 6 h compared to 10 h in sun drying.

The drying characteristics of okra slices were studied for three different drying methods such as sun drying, solar drying and hot air drying. Solar drying was found to be more efficient than sun drying. Hot air drying took the minimum time for maximum removal of moisture. Okra slices dried under 40ºC gave the better results in maintaining better appearance, colour and texture (Wankhade *et al*., 2013)

The product quality is mainly depending on the drying temperature. At lower temperature (40°C), the inactivation of PPO is probably not complete. At higher temperature (60°C), the degradation occurs associated with antioxidants and other nutrients. Tan *et al.* (2013) concluded that Bitter gourd dried at 50°C, significantly increased DPPH scavenging activity, FRAP and TPC values. They suggested that 50°C may be the restricting temperature for hot air drying of Bitter gourd rings. Cabinet drying at 60ºC resulted in high retention of ascorbic acid, chlorophyll, and β-carotene after drying with reduced non-enzymatic browning (Sagar, 2013).

The drying experiment was performed in fixed-bed dryer with upward air flow of sugarcane slices. The drying temperature, relative humidity was maintained at 50 to 60ºC and 17.9 to 11.1 respectively. The time required for sugarcane drying, from an initial moisture content of 70% (wb) to the final moisture content of 6% (wb) was 7.5 and 3.5 h at 50 and 60ºc, respectively.

Experimental data were adjusted to four mathematical models in order to represent the drying process of agricultural products. The Midilli model was the one that best described the sliced sugarcane drying process.

The drying kinetics and colour changes of Bitter gourd at different drying temperature of 50, 60, 70 and 80°C and different thickness 0.5, 0.75 and 1.0 cm were studied by Chen *et al*. (2013). They found that the increase in drying temperature decreased the drying time and increased the total colour change. The increase in thickness increased the drying time. Among all models, Page model gave the best fit.

Bell pepper drying kinetics were studied at different temperatures of 40, 50, 60, 70 and 80°C with air velocity of 2 m/s were found by Taheri-Garavand *et al.* (2011b) . They found that the increase in drying temperature reduces the moisture more rapidly. The effective diffusivity was found higher at the highest temperature with activation energy of 44 KJ/mol, logarithmic model gave the best R^2 and lowest RMSE (Root Mean Square Error) and chi-square.

Drying temperature and air velocity are the main factors in drying. Drying kinetics of Quercus at drying temperature of 50, 60 and 70°C at two air velocity of 0.5 and 1 m/s were investigated by. They reported that at constant drying temperature with increase in air velocity decreases the drying time. Among the selected models, Page model was found to be suitable. The best dried Quercus was obtained at 1m/s dried at 70°C (Tahmasebi *et al.*, 2010).

During drying, relative humidity is maintained throughout the process for better drying efficiency. The drying kinetics of tomato were investigated three different drying temperatures of 40, 60 and 80°C at constant air velocity of 2 m/s maintained at 20%, 40% and 60% RH. They found, at 80ºC the rate of heat and mass transfer is high that reduces the moisture rapidly than 40 and 60 ºC. Midilli *et al.* model was the best model fit for tomato dried at 40, 60 and 80°C (Taheri-Garavand *et al.*, 2011a).

Tan *et al.* (2013) studied the microwave drying on Bitter gourd. The microwave drying at low power level (330W) increased DPPH scavenging activity, FRAP and TPC. Though the drying rate was increased the product quality is not well maintained well in solar drying.

2.3.4 Effects of Pre-treatments on Drying Kinetics

Increase in drying temperature increased the drying rate. However, the drying at higher temperature, leads to loss heat sensitive vitamins and nutrients. Shrinkage was found be a major problem. Therefore, different pre-treatments (blanching, chemical dipping) were applied to fruits and vegetables before drying to reduce the shrinkage and drying time.

The effect of blanching temperature and time combination on drying kinetics of pineapple slices was experimented by Agarry *et al.* (2013). In their study, pineapple slices were blanched at 50, 70 and 80°C for 3,5 and 10 mins. The increase in blanching temperature and time increased the drying time and decreased the effective diffusivity due to gelatinisation of carbohydrate. The logarithmic model describes the best drying behaviour of blanched pineapple slices.

The colour degradation occurred due to blanching at higher temperature. Gupta *et al.* (2014) studied the combination potassium meta bisulphite (KMS) with blanching to retain the colour. The drying kinetics of aonla shreds after blanching with 0.3% KMS at 80°C for 3 minutes was studied by. They found that the blanched aonla shred reduced the drying time by 8-13% than unblanched. And also they reported that blanching retained better colour with increased drying rate and effective moisture diffusivity. Midilli *et al*, was found to be the best model fit for drying of aonla shreds.

In addition to color, the anthocyanin content was also retained by blanching. Garba *et al.* (2015) observed the effect of blanching on drying kinetics and anthocyanin content of black carrot shreds. They reported that the increase in drying temperature increased the drying rate but the blanching had no effect on drying. The anthocyanin content was observed to be higher in blanched black carrot shreds. Among the selected models, page model described the best drying behaviour of blank carrot shreds.

However, water blanching increased the drying characteristics, leaching was the major problem. In order to avoid water due to blanching, Microwave blanching was experimented on various fruits and vegetables with less or no addition of water. Abano and Amoah (2015) reported the effect of microwave (800W) pre-treatment on drying characteristics of white yam. They reported that, microwave before drying had positive effect on drying time but showed negative effect on ascorbic content and non-enzymatic browning. Midilli *et al* gave the best model fit for microwave drying of white yam. Microwave blanching before drying highly reduces the drying time than hot water blanching (Ando *et al.*, 2010).

Chapter 3

Materials and Methods

3.1 Raw material

The Bitter gourds (variety: Pusa hybrid) were procured from the local market and were cleaned properly in running tap water to remove any possible impurities, dirt and surface micro-organisms. Bitter gourds were packed in polyethylene pouches and stored at 4±1ºC until used for experimentation.

Size is an important parameter in processing and it influences various properties. Therefore, to have accurate data, the samples were classified into three categories namely small, medium and large size (Fig 3.1) based on their length. The classification was done based their average dimensions ($\bar{X}$) and the associated standard deviation (σ_x). The grouping was done based on if their particular X dimension satisfies the following inequalities (Pradhan *et al.*, 2010; Sharma *et al.*, 2014). The experimental plan of the work is given in Fig 3.2 and have been explained below.

Small size group: $X < \bar{X} - \sigma_x$ (3.1)

Medium size group: $\bar{X} - \sigma_x < X < \bar{X} + \sigma_x$ (3.2)

Large size group: $X > \bar{X} + \sigma_x$ (3.3)

Figure 3.1: Small, medium and large size Bitter gourds

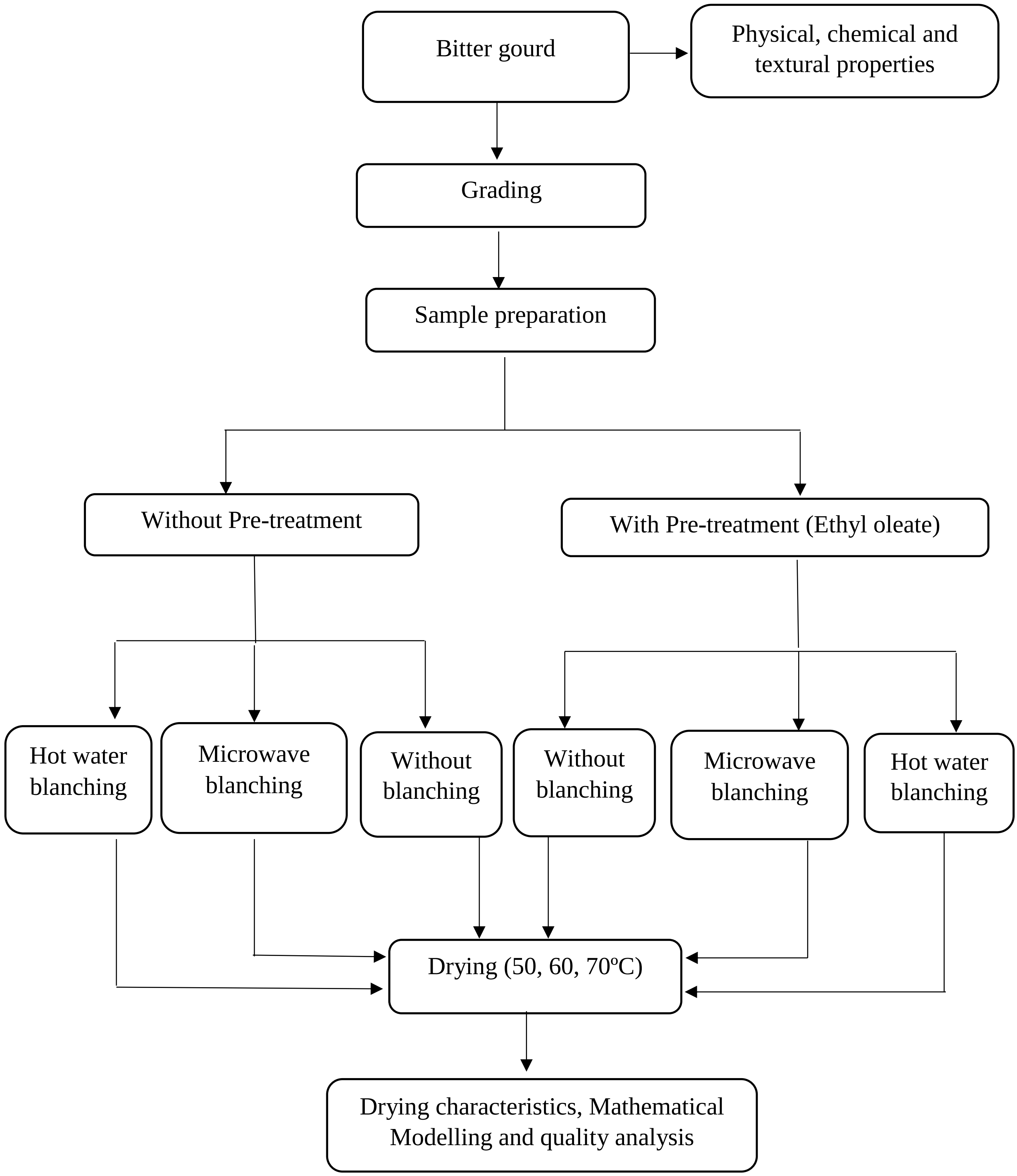

Figure 3.2: Experimental Plan of the Work

3.2 Physical properties

The physical properties of Bitter gourd play an important role in designing equipments for cleaning, sorting, grading, sizing, packing, transportation, storing (post-harvest processing). These findings lead to develop the designs for adequate applications and increase the processing efficacy.

To determine the properties, Bitter gourds were categorized into small, medium and large by statistical analysis of their sizes and the physical properties were measured. Each experiment was replicated thrice for accuracy of the data. Physical properties such as length (L), breadth (B), unit mass (g), geometric mean diameter (GMD), arithmetic mean diameter (AMD), surface area (SA), aspect ratio (AR), sphericity (Φ), volume(V), bulk density (ρ_b), true density (ρ_t), porosity(e) and coefficient of friction (μ) were determined using standard equations as shown below (Pradhan *et al.,* 2010).

$$\text{GMD} = (a\ b\ c)^{1/3} \tag{3.4}$$

$$\text{AMD} = \frac{(a+b+c)}{3} \tag{3.5}$$

$$\text{Surface area} = \pi\,(L^{2/3} \times D^{4/3}) \tag{3.6}$$

$$\text{Aspect ratio} = \frac{b}{a} \tag{3.7}$$

$$\text{Sphericity} = \frac{\text{GMD}}{a} \tag{3.8}$$

where, a is major diameter, b is intermediate diameter, c is minor diameter, L is length D is diameter

The unit mass of Bitter gourd was measured using an analytical balance (Model No: IND/09/08/558, WENSOR, India) having a precision of 0.001g. The bulk density of sample was determined using mass volume relationship by filling a sample in a predetermined weight and volume of the container (500 ml). Bulk density (Eq. 3.9) is calculated from the mass of bulk material divided by volume containing mass (Pradhan *et al*., 2010).

True density was measured using the toluene displacement method (Eq. 3.10). The true density (ρ_t) was taken as the ratio of the unit mass (M) of the sample to the unit volume (V_1) occupied by the sample (Mohsenin, 1980).

Porosity (Eq. 3.11) was determined by using a value of true density and bulk density (Jahromi *et al.,* 2007). The coefficient of static friction (μ) was measured using (Eq. 3.12). Rolling resistance of Bitter gourd was measured for mild steel, glass and plywood using an inclined plane apparatus. The coefficient of friction was calculated by taking tangent angle (Dutta *et al.,* 1988).

$$\rho b = \frac{M}{V} \quad (3.9)$$

$$\rho t = \frac{M}{V_1} \quad (3.10)$$

$$\text{porosity} = \frac{\rho t - \rho b}{\rho t} \text{ X } 100 \quad (3.11)$$

$$\mu = \tan \alpha \quad (3.12)$$

3.3 Chemical properties

Chemical properties were determined at a moisture content of 90±1 % (wb). The sliced bitter gourd pieces (without seeds and pith) were crushed in mortar and pestle and juice was extracted. The juice was analysed for its chemical and proximate analysis. These chemical properties are important in processing of Bitter gourd into value added products like juice, powder, chips etc. Procedures followed for determination of chemical properties are explained below. Analytical grade chemicals were obtained from Sigma Aldrich, India are used.

3.3.1 Moisture determination

Weighed samples (5g) in triplicate were dried for eight hours in a hot air oven at 105ºC (AOAC, 2000) in pre-weighed crucibles. The crucibles were transferred immediately to desiccators, cooled and weighed. The loss in weight represented the moisture content of the samples (Eq.3.13).

$$\text{Moisture content (\%)} = \frac{\text{loss in weight (g)}}{\text{weight of sample (g)}} \text{ X } 100 \quad (3.13)$$

3.3.2 pH

The pH was estimated with the help of a pH meter (Model: LI-617, Elico, India) as referred by AOAC (2000). The equipment was switched on to warm up at least 30 minutes before use. The temperature of the solution to be tested was accurately measured and the temperature control at this temperature was set. The instrument was standardized with a buffer solution of pH 4, 7 and 10. 10 ml of sample was taken and the knob was dipped properly and readings were recorded.

3.3.3 Total Soluble Solids

The total soluble solids (TSS) in the sample (juice) were determined with the help of Abbe type Refractometer and the values were expressed as degree Brix (°B). A temperature of 25ºC was maintained (Gould, 1978)

3.3.4 Titrable Acidity

Two ml fresh juice was taken and diluted with 25 ml of distilled water. An aliquot of 5 ml in triplicate was titrated against 0.1 N sodium hydroxide using phenolphthalein as an indicator. The end point was indicated by the appearance of faint pink. Total acidity was determined followed by AOAC (2000) and calculated using Eq.3.14

$$\text{Acidity (\%)} = \frac{\text{TitreXNormality of alkaliXVolume made upXEquivalent wt of acid}}{\text{volume of sample Xwt of sampleX1000}}\ \text{X100} \tag{3.14}$$

3.3.5 Ash Content

The dried sample (5 g) were weighed in pre-weighed crucibles and charred on a hot plate and then placed in a muffle furnance at 600ºC for 4 hours as referred in AOAC (2000).The ratio of residue left in crucibles after ashing to the intial weight of sample gives the ash content (Eq. 3.15) of the sample.

$$\text{Ash content(\%)} = \frac{\text{weight of residue after ashing(g)}}{\text{wt of sample(g)}}\text{X100} \tag{3.15}$$

3.3.6 Reducing Sugars

Reducing sugars in the sample were estimated by Lane and Eynon's method as referred in Ranganna (1986). Fehling's solution A and B each of 5 ml were taken in a conical flask. The sugar extract was titrated against boiling Fehling's solution by using methylene blue as an indicator. The end point was indicated by the appearance of brick red precipitates. Reducing sugar was calculated using Eq. 3.16.

$$\text{Reducing sugars}(\%) = \frac{\text{mg of invert sugar X Dilution}}{\text{Titre X wt.of sample (g) X 1000}}\ \text{X 100} \tag{3.16}$$

Standard invert sugar solution

9.5 mg sucrose was added into a 1 L volumetric flask containing 100 ml of water and 5 ml concentrated hydrochloric acid. The solution was allowed to stand for three days at room temperature for inversion and then made upto mark by adding water. Factor for Fehling's solution was determined by titrating equal amounts of Fehling's A and B with invert sugar by using methylene blue indicator and the end point was indicated by the complete discoloration of the indicator.

$$\text{Factor for Fehling's solution (g of invert sugar)} = \frac{\text{Titre X 2.5}}{1000} \tag{3.17}$$

mg of invert sugar = g of invert sugar X 1000 (3.18)

3.3.7 Total Sugars

A measured amount of the sample extract was taken in a 100 ml volumetric flask to which 1 ml of concentrated hydrochloric acid was added and kept for hydrolyzation overnight at room temperature. The solution was neutralized with saturated sodium hydroxide solution followed by a drop of phenolphthalein, finally the volume was made upto the mark with distilled water. This solution was then titrated against Fehling's A and B. Total sugars and non-reducing sugar in the product was determined (Fig 3.3) using Eq. 3.19 and 3.20.

$$\text{Total sugar}(\%) = \frac{\text{mg of invert sugar x dilution}}{\text{Titre(after inversion)x wt of sample}}\text{X 100} \tag{3.19}$$

Non-reducing Sugars (%) = [Total Sugar (%) - Reducing Sugar (%)] X 0.95 (3.20)

3.3.8 Crude protein

Crude protein was determined as referred by AOAC (2000) using Kjeldahl apparatus (Fig 3.4) (Pellican Equipments, Model :Classic-Dx-Vats-E). Weighed sample (0.5g) was digested with nitrogen free sulphuric acid (20 ml) using 10 g digestion mixture containing potassium sulphate and copper sulphate (9:1). The contents were cooled and transferred to 100 ml volumetric flask. The volume was made upto the mark with distilled water and mixed. Measured aliquot (10ml) was taken in a distillation flask followed by the addition of 40% NaOH. Liberated ammonia was trapped in hydrochloric acid (0.01N) containing methyl red indicator and then titrated with (0.01 N) sodium hydroxide. Nitrogen present in the sample was used to calculate per cent crude protein by using a factor of 6.25. Total nitrogen content was calculted using Eq. 3.21.

$$\text{Nitrogen}\ (\%) = \frac{\text{sample titre} - \text{blank titre X normality of acid X 14 X 100}}{\text{wt of sampleX1000}} \tag{3.21}$$

$$\text{Crude protein}(\%) = \%\text{nitrogen X } 6.25 \tag{3.22}$$

Figure 3.3: Estimation of Total sugars

Figure 3.4: Estimation of Protein

3.3.9 Fat content

Fat content of fresh sample was detemined as described in AOAC (2000) using socsplus extraction system (Pellican Equipments, Model:Scs-06-As-Dls-Ts). Dried sample (5-10g) was transferred to fat extraction thimble. Fat was extracted using Petroleum ether. The excess solvent was removed and evaporated in a hot air oven. The fat content was calculated using Eq. 3.23

$$\text{Fat}(\%) = \frac{\text{wt of fat(g)}}{\text{wt of sample(g)}} \text{X } 100 \tag{3.23}$$

3.4 Textural Profile Analysis (TPA)

Texture Profile Analysis is a double compression test for determining the textural properties of foods (Fig 3.5). It is occasionally used in many food industries. During a TPA test samples are compressed twice using a texture analyzer to provide insight into how samples behave when chewed. The TPA test was often called the "two bite test" because the texture analyzer mimics the mouth's biting action. The textural profile analysis such as hardness, springiness, cohesiveness, gumminess, chewiness, resilience was determined using a texture analyzer (Model: M/08-371-CT3, Brookfield, USA). All these experiments were replicated for five time for accuracy of the data.

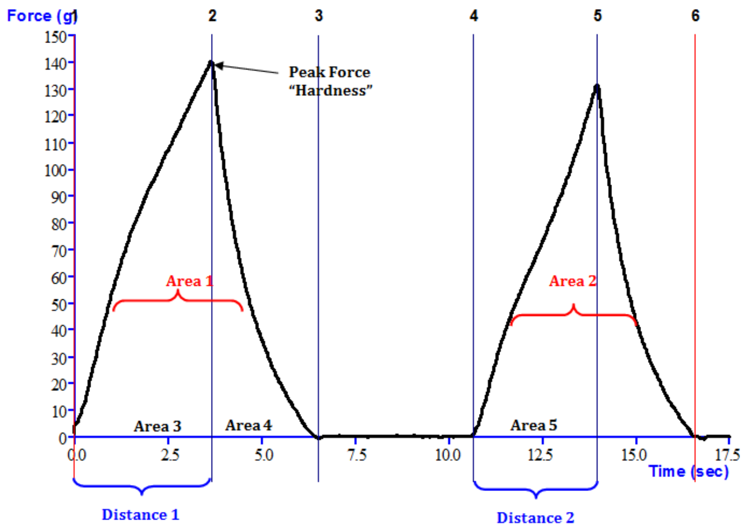

Figure 3.5: Texture Profile Analysis of Food

- Hardness: Force required for a pre-determined deformation. It can be measured by the peak force that occurs during the first compression.
- Springiness: Originally called Elasticity. It is a rate at which a deformed sample returns to its original size and shape. It can be measured by the distance of the detected height during the second compression divided by the original compression distance
- Cohesiveness: Strength of internal bonds in the sample. It can be measured by area of work during the second compression divided by the area of work during the first compression.
- Gumminess: Energy needed to disintegrate a semisolid food until it is ready to swallow. It can be measured by product of hardness and cohesiveness

- Chewiness: Energy needed to chew a solid food until it is ready for swallowing. It can be measured by product of gumminess and springiness.
- Resilience: how well a product fights to regain its original height. It can be measured by withdrawal of the first penetration.

The specifications of texture analyser (Fig 3.6) were maintained during analysing are Cone type probe (TA17), pre-test speed, test speed, post-test speed was maintained at 1, 0.5 and 0.5 mm/s respectively. A load cell of 10000g was used for the purpose and the trigger force was kept at 0.50 N.

Figure 3.6: Texture Analyser

3.5 Pre-treatments

3.5.1 Sample preparation

The uniform size of Bitter gourd was selected. These are washed and sliced for 3.5±1 cm diameter and 0.5±0.1 cm thickness using a manual slicer. The seeds and pith were removed. Pre-treatments viz. Hot water blanching (WB), Microwave blanching (MB), Ethyl oleate treatment (EO), ethyl oleate treated water blanching (EOWB) and ethyl oleate treated microwave blanching (EOMB) were given to the sliced Bitter gourds (Table 1). Samples without any pre-treatment (NOP) was used as the control. After blanching, the samples were cooled down and excess water was removed by muslin cloth. The explanation of each pre-treatments is given in Table 3.1

Table 3.1: Pre-treatments and Methodology

Pre-treatments	Methodology
NOP	Dried without any pretreatment
WB	80ºC for 3 minutes
MB	600W for 135 seconds
EO	2% Ethyl oleate (EO) and 4% Potassium carbonate (K_2CO_3) for 1 min at room temperature
EOWB	Dipped in 2% EO and 4% K_2CO_3 for 1 min at room temperature and water blanched
EOMB	Dipped in 2% EO and 4% K_2CO_3 for 1 min at room temperature and microwave blanched

3.5.2 Blanching effectiveness

Blanching is mainly used to inactivate the enzymatic actions in fruits and vegetable. Peroxidase and Polyphenol Oxidase are the two most heat resistant enzyme need to be inactivated. These enzymes are responsible for discolouration. The blanching conditions vary to product, size and structure. The adequacy of blanching was done by peroxidase test (Ranganna, 1986). 10 g of blanched sample was taken and grinded in mortar and pestle with addition 3-5 ml of water. The mixture was filtered and taken in test tubes containing 20 ml of distilled water, 1 ml of 0.5% guaicol and 1ml of 0.08% of hydrogen peroxide. If there was any colour (brown) development within 3.5 mins then the sample is not adequately blanched. If there was no colour development after 3.5 mins then the sample is completely blanched (Fig 3.7).

Not adequately blanched

Completely blanched

Figure 3.7: Enzyme Inactivation by peroxidase test

3.5.3 Hot water blanching

The blanching temperature and time was optimised in preliminary studies. The sliced Bitter gourds (100 g) were taken. A container was filled with 500 ml of water. The water was allowed to reach the temperature 80ºC. After the steady temperature reached, sliced Bitter gourds were dipped in hot water and allowed to blanch for 3 mins. After blanching the samples were cooled in tap water and surface moisture was removed.

3.5.4 Optimization of power and time in Microwave blanching

Based on the literature studies, the minimum and maximum values of the independent variables (X) were selected. Power (500-700W) and blanching time (90-180s) were considered as independent variables. Enzyme inactivation and Texture (N) were considered as the dependent variables (Y). Central Composite Design of response surface methodology was used to optimize the power and time using Design expert version *7.0* Software (Stat-Ease, Inc., USA). The sliced Bitter gourds (50g) were blanched using domestic microwave oven (LG, Model no:MS2021CW, India). The cavity power absorption was calculated using (Eq. 3.24) where, M_w is mass of water (50 g), M_c is mass of container (250 g), ΔT is the temperature difference and time is the treatment time. The blanched samples were cooled and packed in pouches for drying.

$$\text{Power absorbed(W)} = \frac{4.187\text{XMw}+0.55\text{Mc X}\Delta\text{T}}{\text{time}} \tag{3.24}$$

3.5.5 Ethyl oleate dipping

Ethyl oleate (EO) is an insoluble clear yellow liquid having boiling point >200ºC was purchased from (Sigma Aldrich, India). A solution was prepared by adding 2% EO and 4% Potassium carbonate K_2CO_3 in water (V/V). The sliced samples were dipped into the EO solution for 1 min at room temperature (Fig 3.8). The samples were taken out and surface moisture was removed by muslin cloth.

Figure 3.8: Dipping of Bitter gourd in Ethyl oleate solution

3.6 Drying

All the pre-treated samples each of 50 g, were dried at three different temperatures 50, 60 and 70°C in a tray dryer. The schematic diagram of tray dryer is given in Fig. 3.9. The dryer consists of drying chamber having six aluminium trays, electric finned heater, circulatory fan, temperature sensors and dampers. The pre-treated samples were arranged in a trays and dryer was started 30 mins before the experiment. After the steady temperature reached, the trays were kept inside and moisture loss was observed in an electronic weighing balance (Wensor, India) having 0.001g precision. The relative humidity and air velocity was maintained at 44-55% and 0.8 m/s respectively. The reading was taken every 5 minutes' interval until the sample reach equilibrium moisture content (EMC). The dried Bitter gourd slices were packed in low density polyethylene (LDPE) pouches and stored in the desiccator for further analysis.

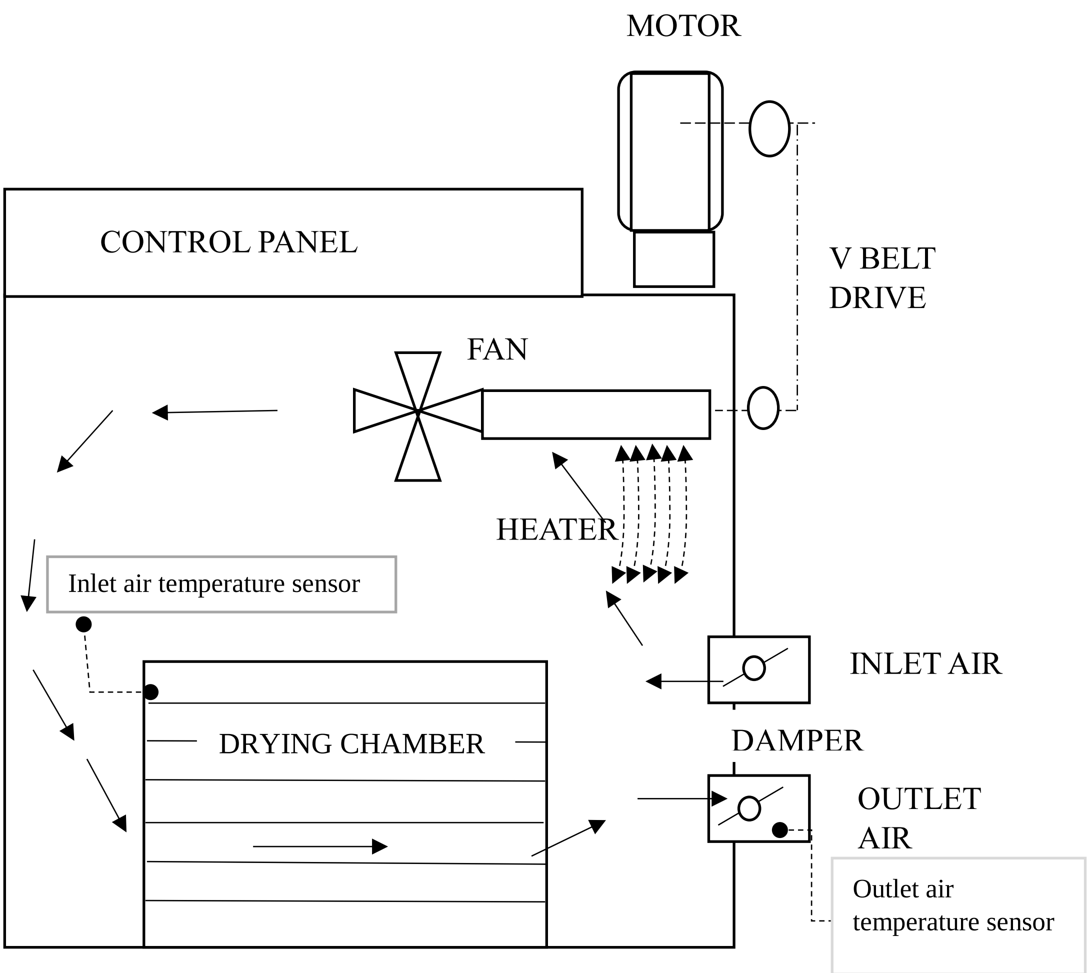

Figure 3.9: Schematic line diagram of tray dryer

3.7 Determination of drying characteristics

3.7.1 Moisture ratio

Moiture ratio was determined using Eq.3.25. As the value of M_e (equilibrium moisture content) is too small as compared to M_t (moisture content at time, t) and M_o (initial moisture content), it has been neglected. The following simplified Equation 3.26 is used to determine the moisture ratio (Motevali *et al.*, 2012)

$$\mathrm{MR} = \frac{\mathrm{Mt-Me}}{\mathrm{Mo-Me}} \tag{3.25}$$

$$\mathrm{MR} = \frac{\mathrm{Mt}}{\mathrm{Mo}} \tag{3.26}$$

3.7.2 Effective diffusivity and Activation energy

The effective moisture diffusivity (D) was determined using Fick's second law of diffusion (Crank, 1975). The slab boundary conditions (Eq.3.27) were assumed for the samples. The following assumptions were considered during drying of the samples. a) transfer of moisture is uniform throughout the sample, b) symmetric mass transfer from the center, c) moisture transfer is due to only by diffusion, and d) resistance of mass transfer in the surface is negligible compared to internal and surface moisture reaches the equilibrium condition. Diffusivity was calculated from the slope (k_0) by plotting Ln (MR) against drying time (Lopez *et al.,* 2000). Activation energy was calculated using Arrehenius equation (Eq. 3.28) by plottting Ln (D) versus 1/Ta. The slope of the straight line gives the activation energy (Lopez *et al.,* 2000)

$$MR = \frac{M_t}{M_0} = \frac{8}{\pi^2}\sum_{n=1}^{\infty}\frac{1}{(2n-1)^2}exp\frac{-(2n-1)^2\pi^2 Dt}{4L^2} \tag{3.27}$$

where, n =1,2,3 no. of terms taken for considerations; t =drying time (min); D = effective moisture diffusivity (m^2/s); L =thickness of sample (cm).

$$\mathrm{D} = \mathrm{Do}\ \exp\frac{-\mathrm{Ea}}{\mathrm{RT}} \tag{3.28}$$

where, D_0 = pre-exponential factor; Ea=activation energy (KJ/mol); R=universal gas constant (J/mol. K); T=Absolute temperature (K)

3.7.3 Shrinkage ratio

Shrinkage is one of the important quality parameters in drying. It has negative consequences on quality of dried products. The change in the shape and structure of must be taken into consideration while predicting temperarure and moisture of the dried product . Shrinkage ratio of dried Bitter gourd was determined using Eq. 3.29 by measuring the sample volume before (V_i) and after (V_f) drying. The sample dimentions were measured using a vernier caliper with an accuracy of 0.01cm (Abasi *et al*., 2009)

$$\text{Shrinkage ratio } = \frac{\text{Vi}-\text{Vf}}{\text{Vi}} \tag{3.29}$$

3.7.4 Rehydration ratio

Rehydration is one of the important drying chacteristics having a significant role in quality, appearance and consumer acceptance of dried samples. Rehydration ratio was calculated using Eq. 3.30. The dried sample (5g) was taken in 100 ml beaker with addition of 80 ml distilled water. The beaker was placed into the hot water bath maintained at 80ºC for 10 mins. The sample was taken out and surface moisture was removed and weighed. The ratio of final (R_f) to initial weight (R_i) gives the rehydration ratio (Abasi *et al.*, 2009)

$$\text{Rehydration ratio} = \frac{\text{Rf}}{\text{Ri}} \tag{3.30}$$

3.7.5 Thin-layer drying models

Thin layer drying kinetics had been studied for various fruits and vegetables. Apricot (Toğrul and Pehlivan, 2003), jujube (Motevali *et al.*, 2012), bell pepper (Taheri-Garavand *et al.*, 2011b), tomato (Taheri-Garavand *et al.*, 2011a). In order to fit the best drying model for Bitter gourd drying, five thin-layer drying models were selected (Table 3.2). The best fit model was selected based on highest coefficient of determination (R^2) and lowest root mean square error (RMSE) and sum of square error (SSE),values.

$$\text{RMSE} = \sqrt{\frac{1}{\text{N}}\sum_{\text{i}=1}^{\text{N}}(\text{MR}_{\text{exp,i}} - \text{MR}_{\text{pre,i}})} \tag{3.31}$$

$$\text{SSE} = \frac{\sum_{\text{i}=1}^{\text{N}}(\text{MR}_{\text{exp,i}}-\text{MR}_{\text{pre,i}}).^2}{\text{N}} \tag{3.32}$$

Table 3.2: Selected thin layer drying models

Model	**Equation**	**References**
Newton	MR=exp(-kt)	Henderson, 1974
Page	MR=exp(-kt^n)	Sarimeseli, 2011
Henderson and pabis	MR= a exp(-kt)	Zhang and Litchfield, 2003
Logarithmic	MR=a exp(-kt)+c	Akpinar *et al.*, 2006
Wang and singh	MR=1+at+bt^2	Wang and Singh, 1978

3.8 Quality analysis

3.8.1 Color measurements

Colour is a primary consumer perceived characteristic. The color values of L* a* b*, Total color difference(ΔE), Chroma and Hue angle were measured for both fresh and dried samples using Hunter Lab (ColorflexEZ; Model No: S/n CFEZ1799, USA) (Fig 3.10).

Figure 3.10: Hunter colour

The equipment was calibrated against white tile (L*= 94.19; a*=-1.38; b*=-0.28) and black tile (L*=0.03; a*=0.02; b*=-0.04). L value indicates towards black (L=0) or white (L=100). Positive and negative 'a' value indicates towards redness or greenness respectively. Positive and negative 'b' value indicates towards yellowness or blueness respectively. The total colour change, Chroma, hue angle was calculated using the following equation (Mohammadi *et al.*, 2008). The reference values indicated as L_0, a_0, b_0. Treated samples are indicated by L, a, b is the. Total colour change (ΔE) is the quality of lightness or darkness. Chroma is the quality of a colour's purity. Hue angle is the common distinction between colours positioned around a color wheel.

$$\Delta E = \sqrt{(L_0 - L)^2 + (a_0 - a)^2 + (b_0 - b)^2} \tag{3.33}$$

$$\text{Chroma} = (a^2 + b^2)^{0.5} \tag{3.34}$$

$$\text{Hue angle} = \tan^{-1}\left(\frac{b}{a}\right) \tag{3.35}$$

3.8.2 Vitamin C

Vitamin C is an important nutrient in the human diet, but it is easily reduced or destroyed by exposure of heat and oxygen during processing. The U.S. Food and Drug Administration requires the Vitamin C content to be listed on the nutrition label of foods. Vitamin C of bitter gourd juice was determined as given in AOAC (2007).

Reagents:

Metaphosphoric acid acetic acid solution: 100 ml of distilled water was taken in 250 ml beaker. 20 ml of acetic acid and 7.5 g metaphosphoric was added and stirred until it dissloves. This solution was diluted to 250 ml with distilled water. The mixture was filtered through fluted filter paper, stored in a bottle and refrigerated until used.

Ascorbic acid standard solution : 50 mg ascorbic acid was weighed and transfered to a 50 mL volumetric flask. It was diluted to the volume with the metaphosphoric acid acetic acid solution.

Indophenol solution dye: 50 ml of distilled water was taken in a 150 ml beaker, 42 mg of sodium bicarbonate and 50 mg of 2, 6-dichloroindophenol sodium salt was added and dissolved. The mixture was diluted to 200 ml with distlled water. The solution wsa filtered through fluted filter paper and transferred to an amber bottle.

Sample preparation :

5 g of dried sample was taken and grinded in Mortar and pestle with addition of 10-15 ml of metaphosphoric acetic acid. The mixture is filtered in a filter paper and transferred into 50 ml volumetric flask. The solution is made up with metaphosphoric acetic acid. 10 ml

of sample was taken and titrated against 2, 6-dichloroindophenol dye. The ascorbic acid of sample was determined using Eq. 3.36 and expressed as mg/100g.

$$\text{mg of AA/ml} = (X - B) \text{ x } (F/E)\backslash\text{x}(V/Y) \quad (3.36)$$

where, X is titre value of sample , B is titre value of blank, F is titre value of dye standardisation, E is amount of sample taken, V is dilution factor, Y is ml of sample taken for titration.

3.8.3 Sample extraction for antioxidant properties

Dried sample (1 g) was extracted with addition of 20-30 ml acetone. The mixture was homogenised in magnetic stirrer for 1 hour. After homogenisation, the solution was centrifuged for 3000 rpm for 20 mins. The aliquot (Fig 3.11) was collected and stored at -20ºC for analysis (Tan *et al.*, 2013).

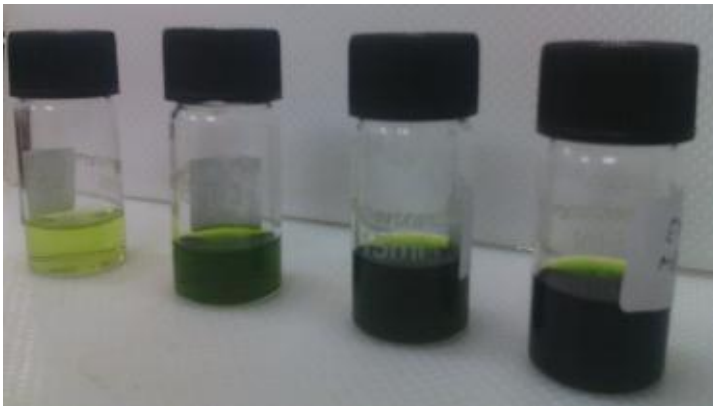

Figure 3.11: Acetone extraction of dried Bitter gourd

3.8.4 Total phenolic compounds (TPC)

Total phenolic compounds of samples were determined using Folin-Ciocalteau (FC) assays Tan *et al*. (2008) with slightly modification. Extracted samples of 500 µl were pipette into test tubes. FC reagent (2 ml) was added into each test tube and was vortexed. Then, the mixtures were left standing at room temperature for 5 mins. An amount of 1.6 ml 7.5% Na_2CO_3 were added into the mixture and vortexed again. The mixtures were allowed to stand for 1 hour in dark at room temperature. The absorbance was measured at 765 nm using UV-visible spectrophotometer and calibration curve was prepared using gallic acid at the concentration of 0,0.1, 0.3, 0.5, 0.7, 0.9 and 1.0 mg/ml (R^2 =0.999). Results were expressed as mg gallic acid equivalents (GAE)/100g of dried sample.

3.8.5 Diphenyl Picryl Hydroxyl (DPPH)

DPPH scavenging activity of Bitter gourd was determined according to the method of Tan *et al*. (2008). A stock solution of DPPH was prepared by dissolving 4 mg in 100 ml methanol and stored at -20°C until used. A working standard was prepared by mixing 35 ml of stock solution with 35 ml of methanol and absorbance was observed at 516 nm using a spectrophotometer. 100 µL of Bitter gourd extract was mixed with 1.5 ml of methanolic DPPH and kept overnight in the dark and absorbance was taken at 516 nm. The DPPH scavenging activity was determined using Eq. 3.37.

$$\text{DPPH scavenging activity}(\%) = \frac{blank\ A - sample\ A}{blank\ A}\ X100 \qquad (3.37)$$

3.8.6 Ferric Reducing Antioxidant Power (FRAP)

The FRAP (Ferric reducing antioxidant power) assay was determined according to the method of Musa *et al*. (2011). The principle of this method is based on the reduction of the ferric- tripyridyl triazine complex to its ferrous coloured form in the presence of antioxidants. FRAP working reagent was prepared using 300 mM acetate buffer (3.1 g sodium acetate trihydrate, 16 ml glacial acetic acid made up to 1:1 with distilled water, pH 3.6), 10 mM 2,4,6-tris (2-pyridyl)-s-triazine (TPTZ) in 40 mM HCl and 20 mM ferric chloride ($FeCl_3.6H_20$) in the ratio of 10:1:1. It was prepared freshly and set at 37°C.

Aliquots of 50 µL sample supernatant were mixed with 1.5 mL FRAP reagent and the absorbance of reaction mixture at 595 nm was measured spectrophotometrically after incubation at 37°C for 10 min. To construct the calibration curve five concentrations of Trolox were used and the absorbencies were measured as sample solution (R^2=0.9968). The results were expressed as Trolox equivalent per 100 g of dried Bitter gourd (mg of TAE/100 g of DW). All the measurements were taken in triplicate and expressed as mean value ± SD.

3.9 Statistical analysis

All experiments were carried out in triplicate. All results were statistically analysed using IBM SPSS STATISTICS (Ver-21, USA). Univariate analysis of variance (ANOVA) was determined using Tukey's HSD test with mean and standard deviation. The experimental data were fitted into the models using MATLAB (Ver-2011b, Mathworks, USA).

Chapter 4

Results and Discussion

4.1 Properties of Bitter gourd

Information on various physical, chemical and textural properties of Bitter gourd is required to optimize processing equipment and post-harvest operations. Various properties of the said vegetable were determined using standard procedure.

4.1.1 Physical Properties

The physical properties of pusa hybrid variety of three different sizes were shown in Table 4.1. The properties were determined at a constant moisture content of 91±1 % (wb). The length, breadth and unit mass ranged from 4.80±1.05 to 13.83±1.90 cm, 3.03±0.65 to 4.11±0.55 cm, 13.62±2.35 to 84.87±4.51 g respectively.

Table 4.1: Physical properties of Bitter gourd

Physical properties	**N**	**Small**	**Medium**	**Large**
Length (cm)	100	4.80(±1.05)[a]	8.46(±2.35)[a]	13.83(±1.90)[b]
Breadth (cm)	100	3.03(±0.65)[a]	3.81(±1.40)[a]	4.11(±0.55)[a]
Unit mass (g)	100	13.62(±2.35)[a]	29.25(±3.32)[a]	84.87(±4.51)[b]
GMD (cm)	100	3.15(±0.43)[a]	3.56(±0.39)[a]	4.13(±0.37)[a]
AMD(cm)	100	3.17(±0.43)[a]	3.62(±0.38)[ab]	4.20(±0.33)[b]
Sphericity	100	85.06(±2.18)[a]	81.08(±1.07)[a]	80.00(±1.45)[a]
Surface area (cm^2)	100	38.96(±3.36)[a]	81.36(±3.17)[a]	122.56(±5.09)[a]
Aspect Ratio	100	88.00(±2.26)[a]	80.96(±3.51)[a]	81.76(±3.97)[a]
Volume (cm^3)	10	23.00(±2.88)[a]	50.00(±5.00)[b]	96.66(±5.37)[c]
Bulk density (g/cm^3)	10	0.70(±0.14)[a]	0.85(±0.06)[a]	0.92(±1.46)[a]
True density (g/cm^3)	10	1.30(±0.48)[a]	1.28(±0.32)[a]	1.28(±0.11)[a]
Porosity (%)	10	26.19(±0.65)[a]	29.06(±0.31)[b]	30.30(±1.06)[c]
Coeff. of friction				
mild steel	10	3.17(±1.88)[a]	3.47(±0.62)[a]	4.36(±1.17)[a]
Glass	10	1.23(±1.22)[a]	2.18(±0.74)[a]	2.83(±0.84)[a]
Plywood	10	2.22(±1.83)[a]	2.43(±1.37)[a]	3.52(±1.42)[a]

N: No.of. Observations; Values in the bracket with ± indicates standard deviation
*same letters in a rows indicates no significant (P>0.05) difference in physical properties

Sphericity of small Bitter gourds was 85.06±2.18%. This higher value of sphericity indicates for almost spherical shape of the small Bitter gourds (Dutta *et al*., 1988). However, large size Bitter gourd had lower value of sphericity (80 ±1.45%).

The coefficient of static friction was determined for mild steel, glass and plywood. It was highest for mild steel (3.17 to 4.36) and lowest for glass (1.23 to 2.83). The data shows (Table 3) that length, unit mass, surface area, volume and porosity properties had significant difference ($P<0.05$). These properties increased with size. Other properties did not show significant ($P>0.05$) difference among small, medium and large size Bitter gourd.

4.1.2 Chemical properties

Chemical properties are shown in Table 4.2. The Pusa hybrid variety was found to have similar moisture and acidity value as that in Phule Green Gold Cultivar Bitter gourd, but higher in total sugar, ash and TSS (Satkar *et al.*, 2013). The ascorbic acid content of Pusa hybrid Bitter gourd was higher (94mg/100g) than that reported by Myojin *et al.* (2008). The higher fat and lower protein percentage was found in Pusa hybrid when compared to other variety of Bitter gourd (Saeed *et al.*, 2010).

Table 4.2: Chemical properties of Bitter gourd

Properties	**Value**
Moisture (wb %)	91.92(±1.12)
Reducing sugar (%)	2.5(±0.52)
Total sugar (%)	4.4(±0.64)
Fat (%)	0.58(±0.12)
Protein (%)	11.2(±0.92)
Ash content (%)	1.6(±0.13)
pH	6.082(±0.02)
TSS (ºBrix)	3.79(±0.08)
TDS (ppm)	12.9(±0.73)
Acidity (%)	0.035(±0.001)
Vitamin C (mg/100g)	94.14(±1.0)

N: No of observations; Values in the bracket with ± indicates standard deviation

4.1.3 Texture profile analysis

The results for texture profile analysis of Bitter gourd is given in Table 4.3. TPA performs two count cycles to determine hardness, Cohesiveness, Springiness, Gumminess and Resilience. The distance travelled by probe (mm) against Load (N) for small, medium and large size Bitter gourds are shown in Fig.4.1- 4.3. The highest peak indicates the hardness of Bitter gourd. Average hardness of small and big size Bitter gourds was 41.15±1.98 N and 81.24±0.97 N respectively. The corresponding value for a similar kind of vegetable i.e. Zucchini was 19.82 N (Gholami *et al.*, 2012). It was also observed that pusa hybrid Bitter gourds have lower cohesiveness and resilience but higher springiness and chewiness than zucchini and carrots. There were significant differences (P<0.05) in textural properties among small, medium and large Bitter gourd.

Table 4.3: Texture Profile Analysis of Bitter gourd

TPA	Small	Medium	Large
Hardness (N)	41.15(±1.98)^{a}	80.12(±1.78)^{b}	81.24(±0.97)^{c}
Resilience	0.04(±0.01)^{a}	0.05(±0.005)^{a}	0.07(±0.01)^{a}
Cohesiveness	0.18(±0.02)^{a}	0.22(±0.03)^{a}	0.24(±0.01)^{a}
Springiness (m)	12.64(±0.45)^{a}	18.44(±1.17)^{b}	20.24(±1.98)^{b}
Gumminess(N)	10.92(±2.23)^{a}	16.01(±1.64)^{b}	16.99(±1.76)^{b}
Chewiness(J)	0.07(±0.02)^{a}	0.29(±0.04)^{b}	0.34(±0.04)^{b}

N: No. of observations; Values in the bracket with ± indicates standard deviation
*Same letters in a row indicates, there is no significant difference (P>0.05)
*Different letters in a row indicates there is a significant difference (P<0.05)

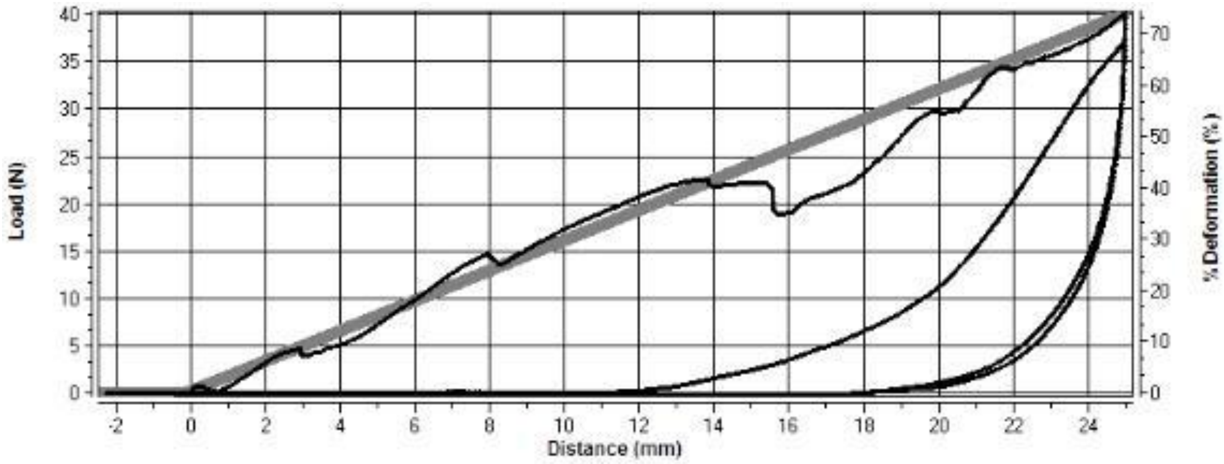

Figure 4.1: TPA of small size Bitter gourd

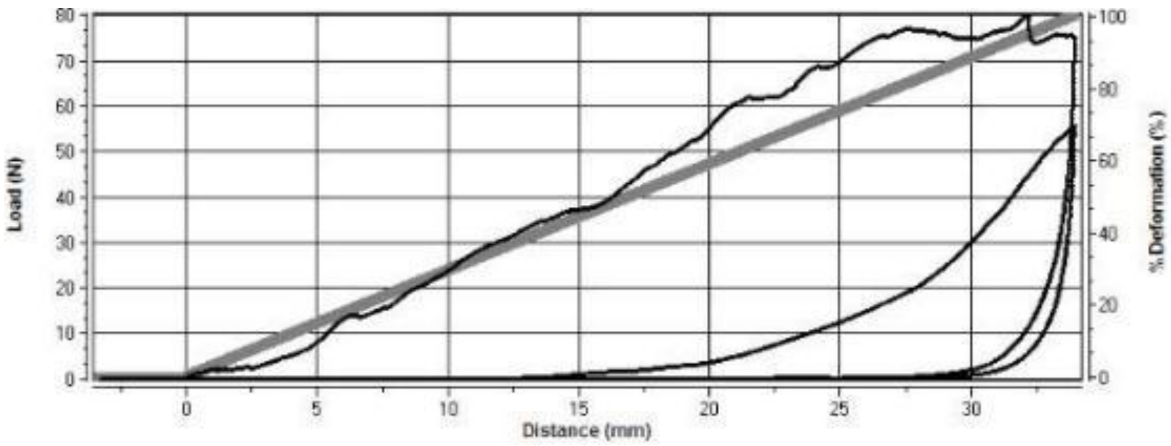

Figure 4.2: TPA of medium size Bitter gourd

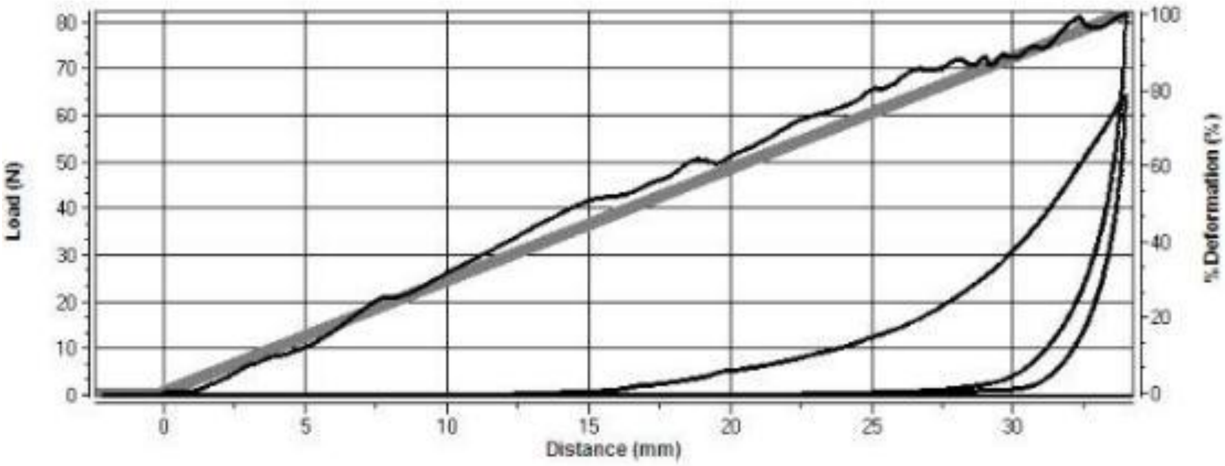

Figure 4.3: TPA of large size Bitter gourd

4.2 Optimization of power and time for microwave blanching

Blanching effectiveness was optimum at 80ºC and 3 mins for water blanching. Central composite design (Table 4.4) suggested that 600 W and 135 s were the optimum conditions for microwave blanching. In this study, texture and blanching effectiveness were considered as response parameter. The other response parameters such as colour, enzyme inactivation rate and Vitamin C were also investigated.

Table 4.4: Optimization of power and time for microwave blanching

S.no	Power (w)	Time (s)	Texture (N)	Blanching effectiveness
1	500	180	5.893	Blanched
2	600	90	8.823	Not blanched
3	700	135	6.013	Blanched
4	600	135	9.103	Blanched
5	600	135	9.050	Blanched
6	600	135	9.050	Blanched
7	700	90	8.995	Not blanched
8	500	135	14.51	Not blanched
9	600	135	9.124	Blanched
10	500	90	18.20	Not blanched
11	700	180	8.377	Blanched
12	600	180	8.125	Blanched
13	600	135	9.073	Blanched

4.3 Effects of Pre-treatments and Drying Temperature on Drying Characteristics

4.3.1 Effect on moisture ratio and drying rate

The moisture ratio curve for all pre-treated and control samples dried at 50, 60 and 70ºC are shown in Fig 4.4 to 4.6. All the samples were dried to the final moisture content of 5-6 % from an initial moisture of 90 % (wb). The drying time for samples without any pretreatment (NOP) and after treatments such as water blanching (WB), microwave blanching (MB), ethyl oleate treated (EO), ethyl oleate treated water blanched (EOWB) and ethyl oleate treated microwave blanched (EOMB) was 270, 260, 240, 230, 210 and 190 min respectively at 50ºC. There was a significant ($P<0.05$) reduction in drying time with all pre-treatments.

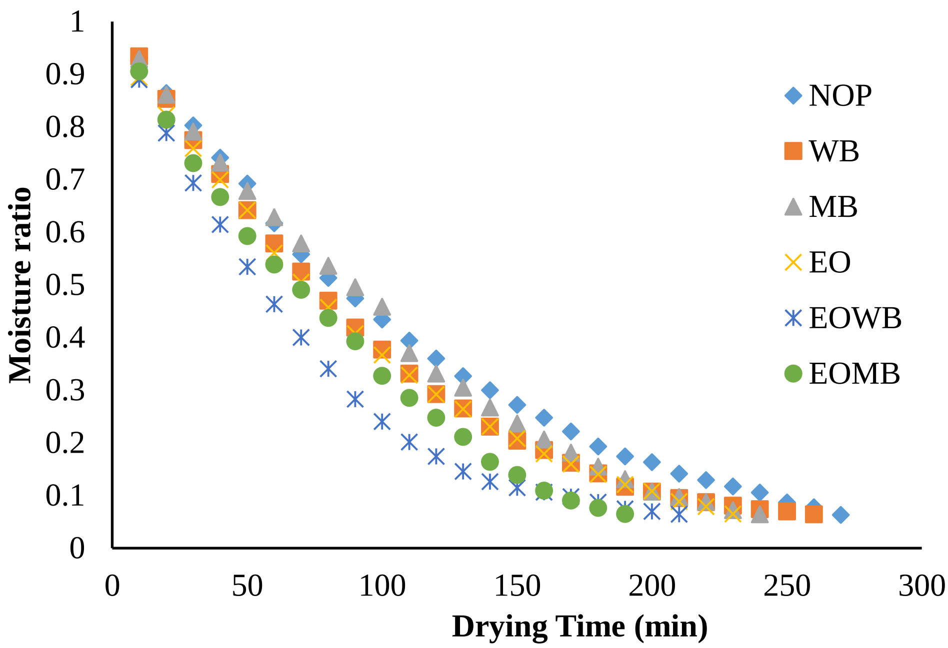

Figure 4.4: Moisture ratio for NOP, WB, MB, EO, EOWB and EOMB at 50ºC

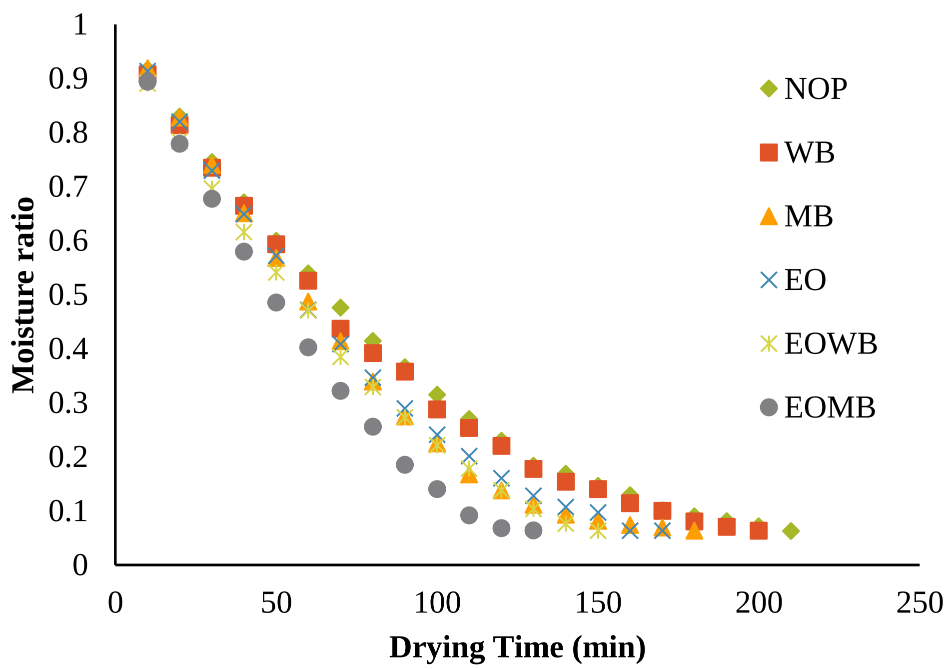

Figure 4.5: Moisture ratio for NOP, WB, MB, EO, EOWB and EOMB at 60ºC

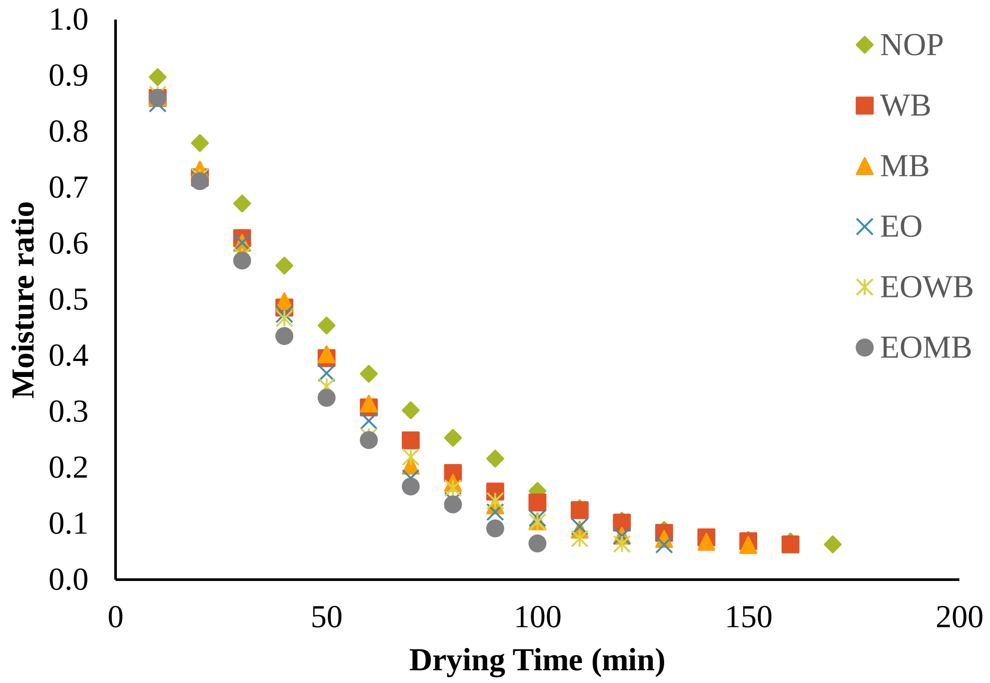

Figure 4.6: Moisture ratio for NOP, WB, MB, EO, EOWB and EOMB at 70ºC

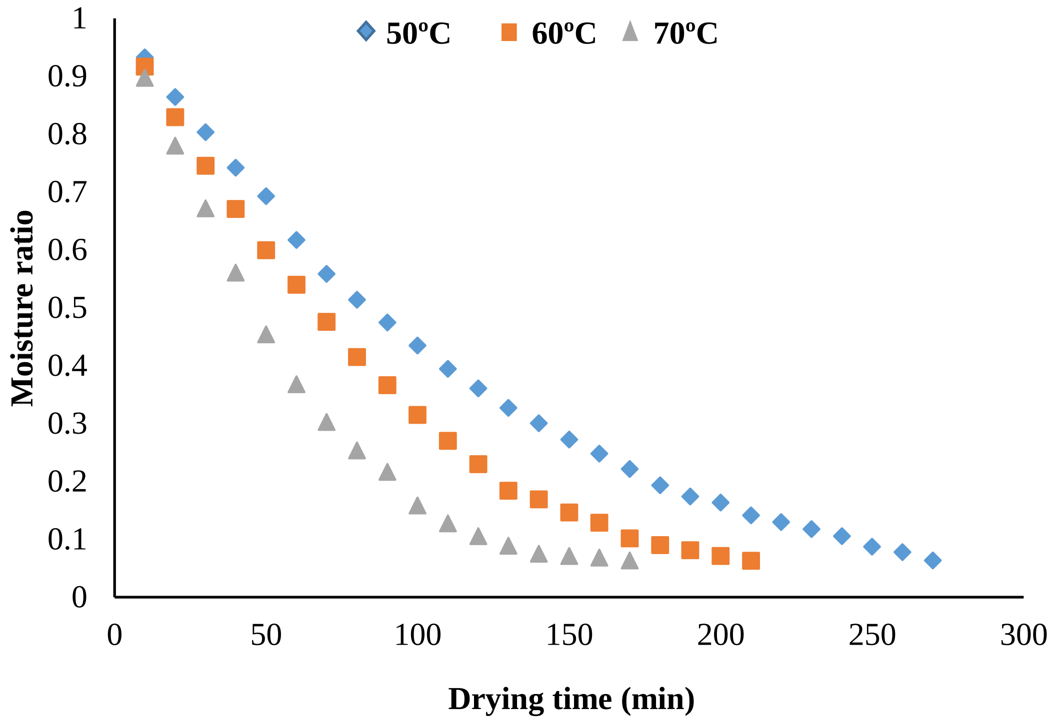

Figure 4.7: Effect of temperature on moisture ratio for NOP samples

The reduction in drying time for EO treated samples was found to be higher than water and microwave blanched samples. This is due to the dipping of sliced Bitter gourd in EO solution dissolving the waxy layer around the sample and creating pores which improves moisture diffusion at a faster rate. Similar results were reported in drying of apricots (Doymaz, 2004), red pepper (Doymaz and Pala 2002), ginger (Deshmukh *et al*. 2013) and grapes (Pangavhane *et al*. 1999).

However, the combined pre-treatment of ethyl oleate and subsequent water and microwave blanching showed the greater response in moisture ratio. The overall drying time was reduced maximum by EOMB. It is due to the combined effect of blanching and EO accelerating the moisture diffusion more effectively during drying.

The reduction in moisture ratio was dependent on both drying temperature and time. The effect of drying temperature on moisture ratio for not pre-treated sample is shown in Fig. 4.7. The increase in drying temperature from 50 to 70ºC decreased the drying time from 270 to 190 min. The same results were reported during Bitter gourd drying at 50 to 80ºC (Chen *et al*. 2013). It is due to faster evaporation rate of water at higher temperature through heat transfer. All the pre-treatments and temperature were significantly ($P<0.05$) affected the moisture ratio of dried Bitter gourd.

The drying rate curves for all pre-treated and control sample dried at 50, 60 and 70ºC are shown Fig.4.8-4.10. It can be observed that the drying rate for all the samples followed the falling rate period. This indicates that the diffusion was completely controlled by water diffusion (Chen *et al.*, 2013). The drying rate was accelerated maximum by ethyl oleate treated and microwave blanched sample. It is due to the dipping of samples in ethyl oleate creates pores for diffusion that increases the permeability of cell walls to promote the faster moisture removal. It was observed that the drying rate was maximum in the initial stage and gradually decreases as time passes. And also it was observed that the increase in temperature increases the drying rate.

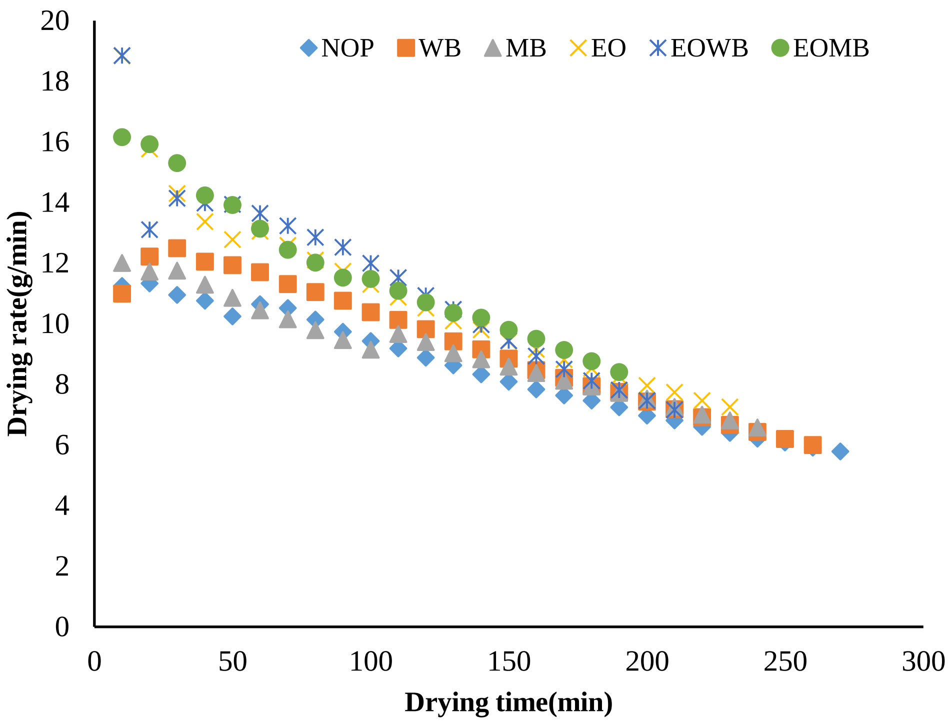

Figure 4.8: Drying rate curve for NOP, WB, MB, EO, EOWB and EOMB at 50ºC

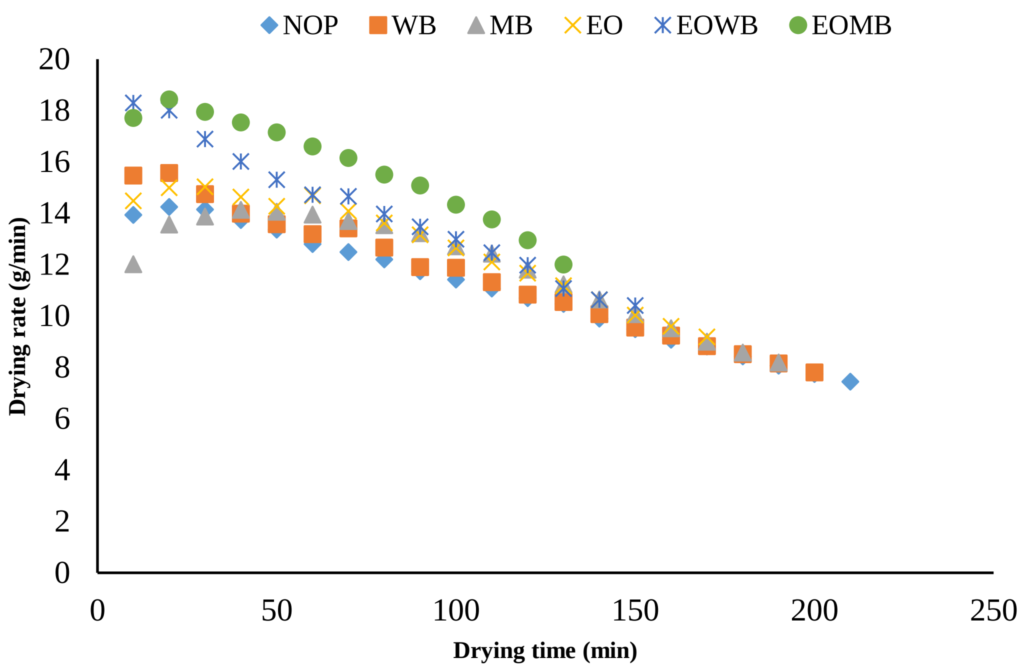

Figure 4.9: Drying rate curve for NOP, WB, MB, EO, EOWB and EOMB at 60ºC

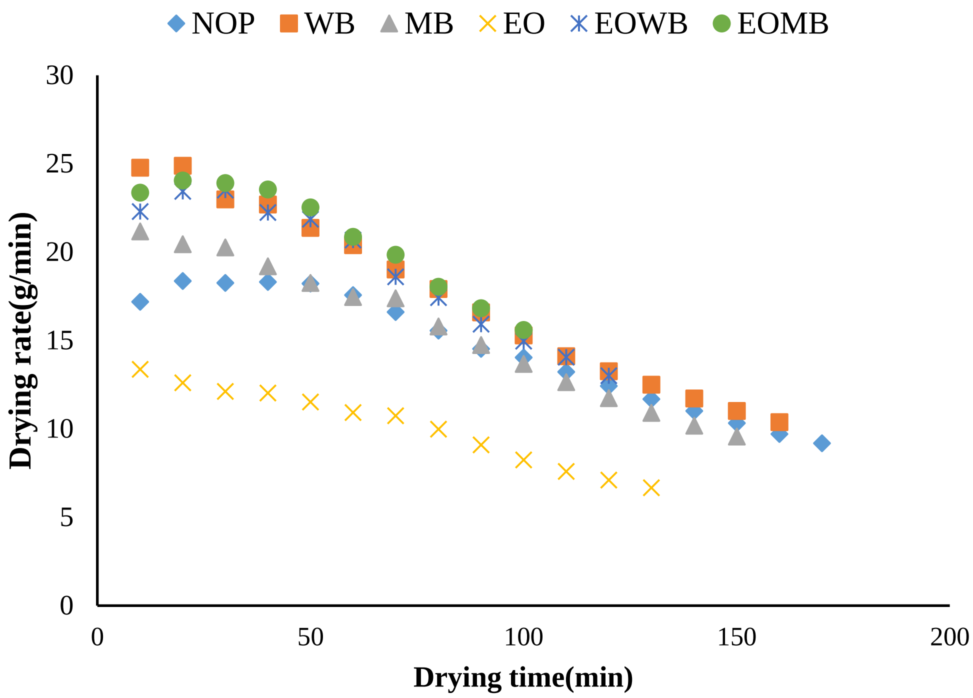

Figure 4.10: Drying rate curve for NOP, WB, MB, EO, EOWB and EOMB at 70ºC

The increase in temperature from 50 to 70ºC increased the drying rate for all samples. The effect of drying temperature on drying rate for not pre-treated sample is shown in Fig 4.11. Both the pre-treatments and drying temperature significantly ($P<0.05$) increased the drying rate.

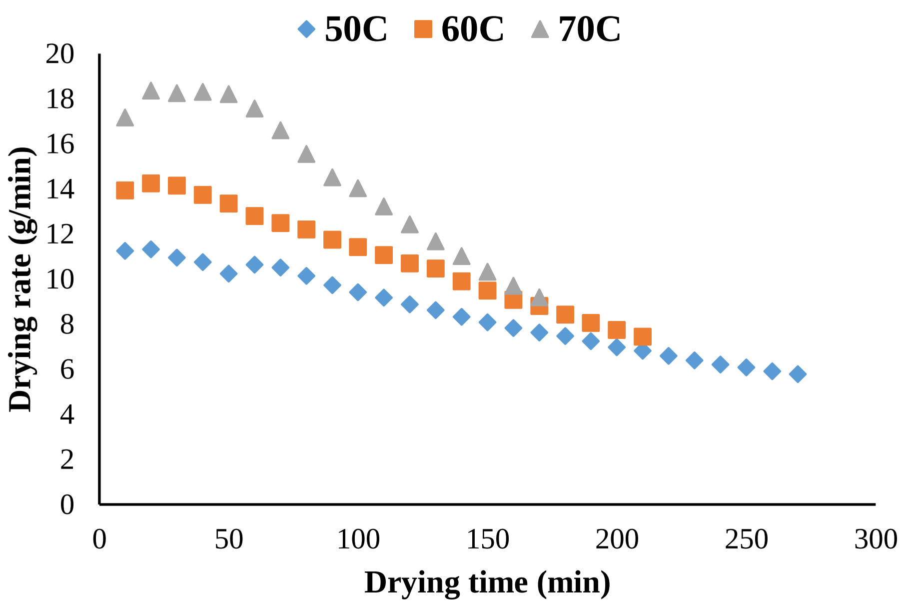

Figure 4.11: Effect of temperature on drying rate for NOP samples

4.3.2 Effect on diffusivity and activation energy

Effective diffusivity of agricultural products falls in the range of 10^{-12} to 10^{-8} (Wang *et al*., 2007). Diffusivity values for all dried samples was found to be 10^{-8} m^2/s. The combined effect of pre-treatment and drying temperature on moisture diffusivity for all samples is given in Fig 4.12. The increase in temperature increased the moisture diffusivity. As the temperature increased from 50 to 70ºC, diffusivity increased from 2.65 to 4.85 x10^{-8} for not pre-treated samples. The moisture diffusivity for all pre-treated and control samples dried at 50, 60, 70 ºC are given in Fig 4.13 to 4.15 respectively. All the samples dried at three different temperatures showed the falling rate curve. Thus the diffusion was completely controlled by interior water diffusion. These results were matched Bitter gourd dried at 50, 60, 70 and 80ºC (Chen *et al*., 2013).

The moisture diffusivity was found higher (7.48 x10^{-8}) in ethyl oleate treated and microwave blanched samples dried at 70ºC. Whereas the lower diffusivity (4.85 x10^{-8}) was found in not pre-treated samples dried at same temperature. This is because, ethyl oleate and microwave pre-treatment increased the drying rate with faster moisture removal compared to not pre-treated samples (Siva Kumar *et al*., 2013). There was a significant ($P<0.05$) effect of pre-treatments and temperature on diffusivity.

The activation energy for all samples was calculated using Arrhenius-type equation (Table 4.5). The graph was plotted logarithm of diffusivity against absolute temperature for all pre-treated and control samples (Fig 4.16). The result showed a linear relationship for all samples with R^2 value 0.96-0.99. The activation energy of not pre-treated and ethyl oleate treated microwave blanched sample was 27.80 kJ/mol and 30.55 kJ/mol respectively. The calculated activation energy for all samples were matched with findings of Siva Kumar *et al.* (2013) for high moisture vegetables.

Table 4.5: Values of R^2 and activation energy

Pre-treatments	R^2	**Activation energy(KJ/mol)**
NOP	0.9983	27.808
WB	0.9986	22.440
MB	0.9873	26.501
EO	0.9984	30.343
EOWB	0.9999	25.158
EOMB	0.9673	30.558

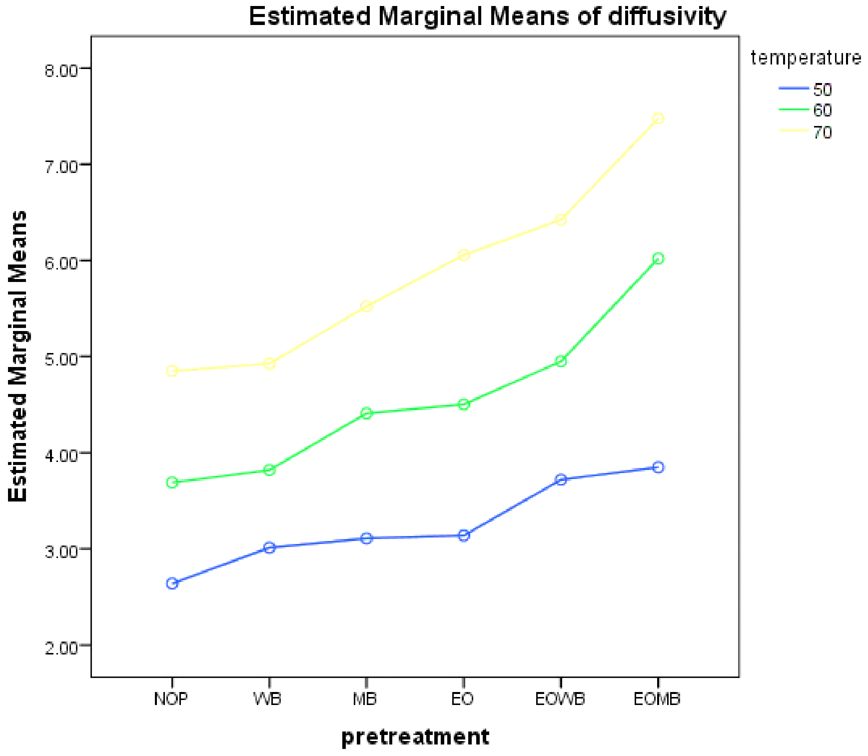

Figure 4.12: Combined effect of pre-treatment and temperature on diffusivity

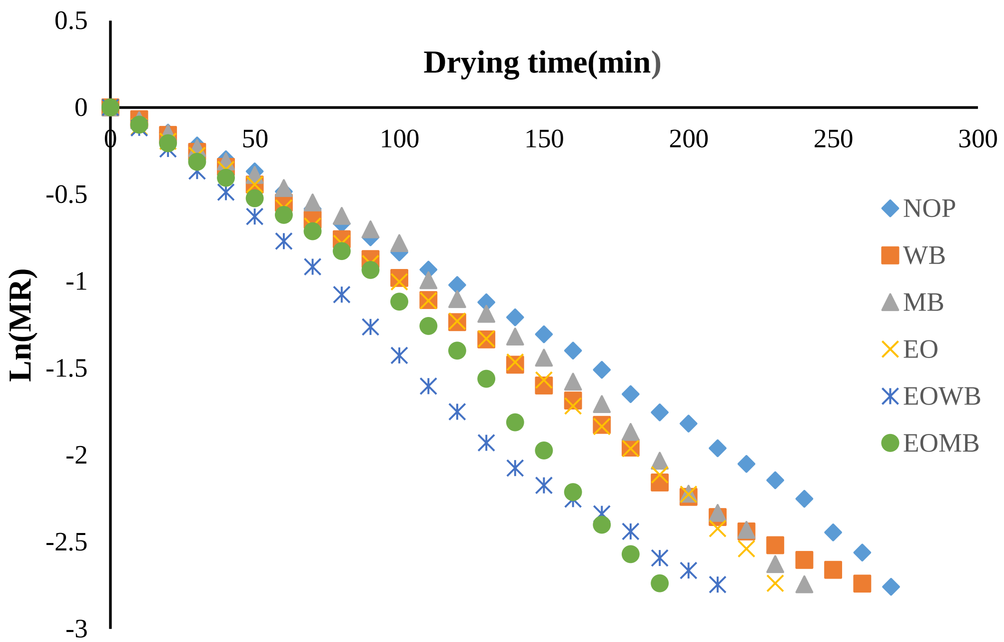

Figure 4.13: Effective diffusivity for NOP, WB, MB, EO, EOWB, EOMB at 50°C

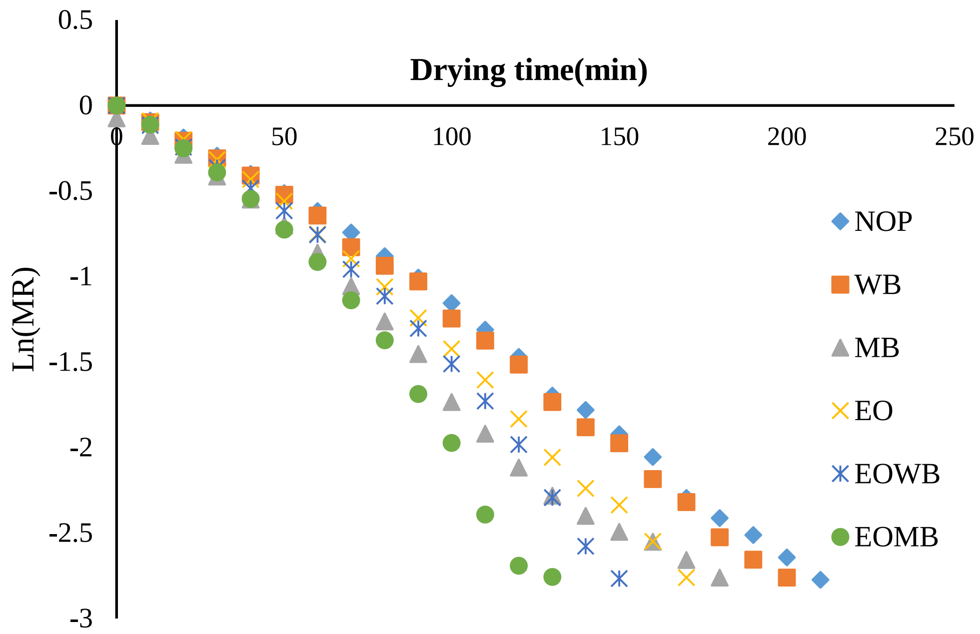

Figure 4.14: Effective diffusivity for NOP, WB, MB, EO, EOWB, EOMB at 60ºC

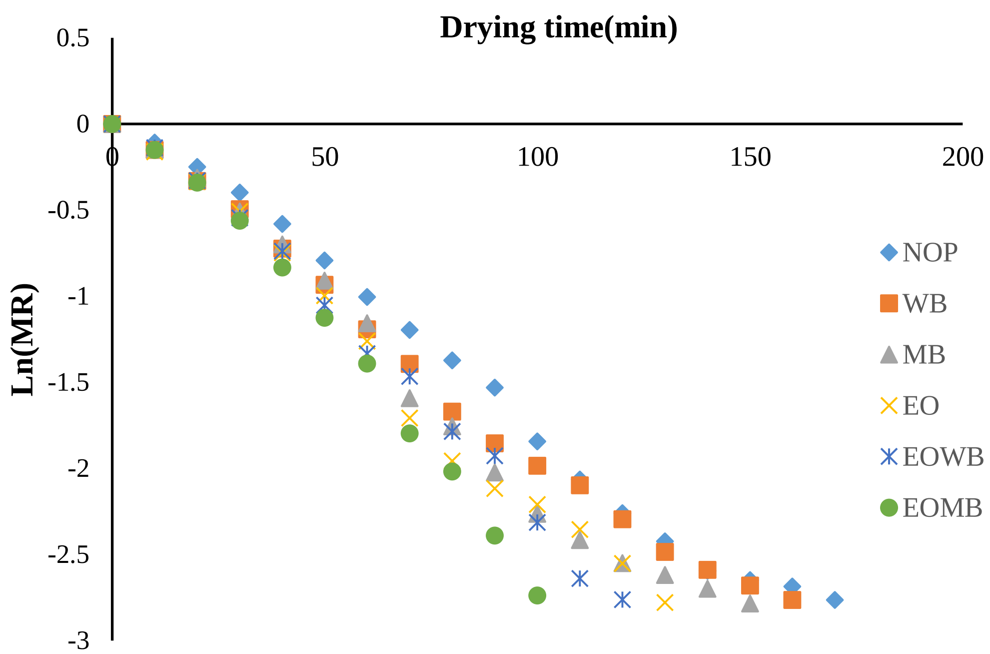

Figure 4.15: Effective diffusivity for NOP, WB, MB, EO, EOWB, EOMB at 70ºC

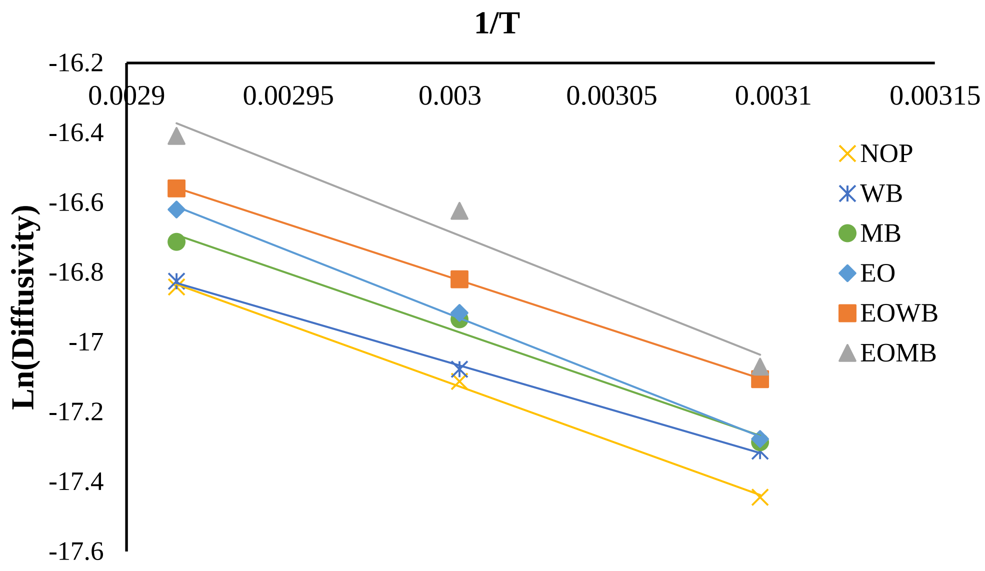

Figure 4.16: Activation energy for all pre-treated samples

4.3.3 Effect on shrinkage and rehydration ratio

Shrinkage and rehydration ratio are the two important drying characteristics. These two values have significant role in quality, appearance and consumer acceptance of dried samples. The combined effect of pre-treatment and drying temperature on shrinkage ratio for all samples is given in Fig 4.17.

Temperature had significant ($P<0.05$) effect on shrinkage ratio. The increase in temperature from 50 to 70ºC increased the shrinkage ratio from 70.30 to 80.2 %. The same results were reported on shrinkage of onion by Abasi *et al.* (2009). They also revealed, drying at higher temperature increases the contractile stress in the cellular structure that cause shrinkage in the tissues.

The shrinkage and rehydration ratio for all samples dried at 50, 60 and 70ºC are given in Table 4.6. All pre-treatments had significant ($P<0.05$) effect on shrinkage ratio. The higher shrinkage ratio (80.2%) was found in not pre-treated samples and lower shrinkage ratio (52.06%) was found in EOMB treated samples dried at 70ºC. EOMB samples dried at lowest temperature (50ºC) showed the lowermost shrinkage ratio (46.04%).

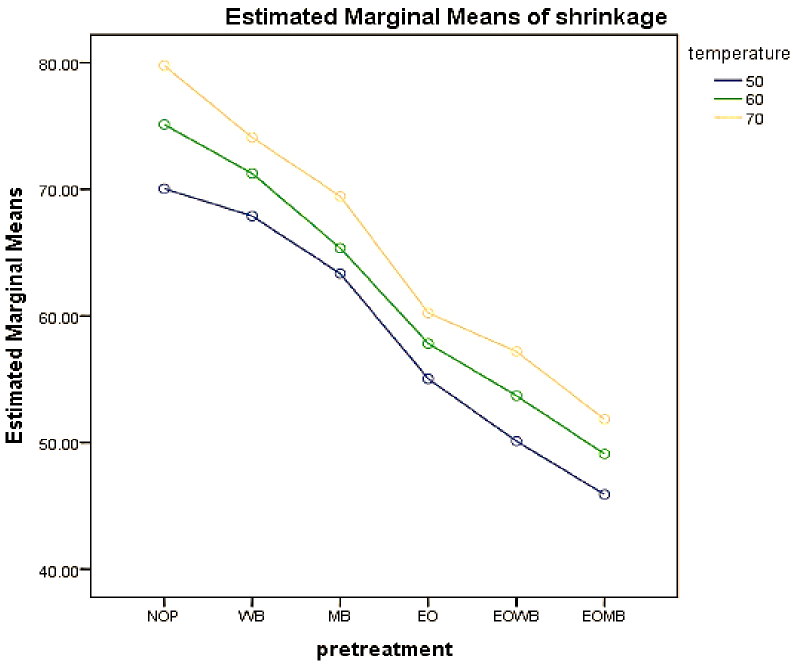

Figure 4.17: Combined effect of pre-treatment and temperature on shrinkage

This is due to dipping samples in ethyl oleate and subsequent microwave blanching reducing the contractile stress and maintaining the cell structure during drying. The combined effect of pre-treatment and drying temperature on rehydration ratio for all samples is given in Fig 4.18. The rehydration ratio increased (3.49 to 4.90 x10^{-8}) as the temperature increased from 50 to 70ºC for NOP samples. The results were matched with Abasi *et al.* (2009). They stated that cellular tissue becomes more porous at higher temperature for absorbing maximum water. There was significant ($P<0.05$) effect of combined temperature and pre-treatments on rehydration ratio.

The rehydration ratio for all pre-treated samples and control samples are given in Table 4.6. The rehydration ratio was maximum in EOMB treated samples followed by EOWB, EO MB, WB and NOP. Out of all treatments, EOMB treated samples showed the highest rehydration ratio. It is due to treating of sliced Bitter gourds in EO and subsequent blanching. This combined treatments aids to releases an air from tissues and creates porous structure that results in maximum absorption of water.

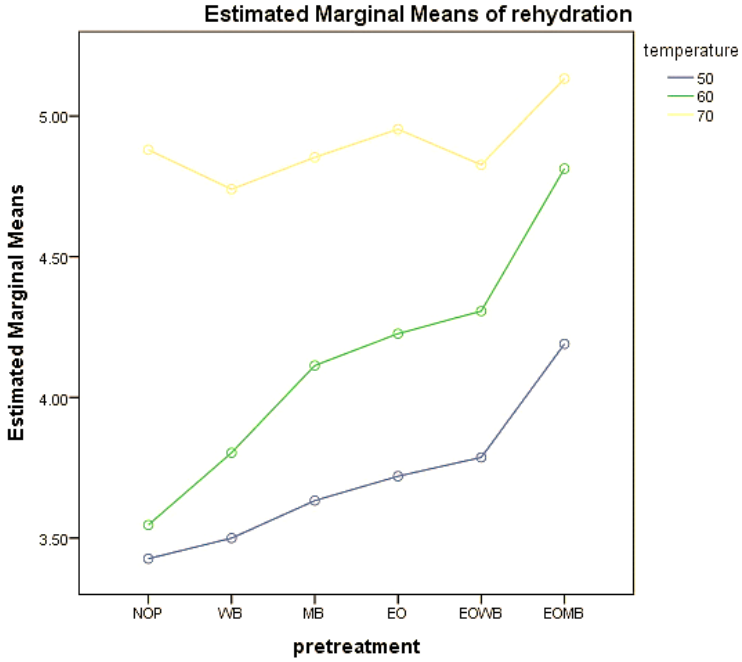

Figure 4.18: Combined effect of pre-treatment and temperature on rehydration

Table 4.6: Effect of Pre-treatment and drying temperature on diffusivity, shrinkage and rehydration ratio

Pre-treatments	Drying temperature	Diffusivity ($x10^{-8}$ m^2/s)	Shrinkage ratio (%)	Rehydration ratio (%)
NOP	50ºC	2.65^{aA}	70.30^{fA}	3.49^{aA}
WB		3.03^{bA}	68.04^{eA}	3.51^{bA}
MB		3.11^{cA}	63.90^{dA}	3.68^{bA}
EO		3.14^{dA}	55.50^{cA}	3.72^{cA}
EOWB		3.72^{eA}	50.46^{bA}	3.81^{cA}
EOMB		3.86^{fA}	46.04^{aA}	4.21^{dA}
NOP	60ºC	3.70^{aB}	75.41^{fB}	3.59^{aB}
WB		3.83^{bB}	71.93^{eB}	3.83^{bB}
MB		4.42^{cB}	65.99^{dB}	4.16^{bB}
EO		4.5^{dB}	57.92^{cB}	4.34^{cB}
EOWB		4.96^{eB}	53.92^{bB}	4.29^{cB}
EOMB		6.03^{fB}	49.34^{aB}	4.85^{dB}
NOP	70ºC	4.85^{aC}	80.20^{fC}	4.90^{aC}
WB		4.93^{bC}	74.40^{eC}	4.76^{bC}
MB		5.52^{cC}	69.84^{dC}	4.23^{bC}
EO		6.06^{dC}	60.23^{cC}	4.98^{cC}
EOWB		6.43^{eC}	57.85^{bC}	4.85^{cC}
EOMB		7.48^{fC}	52.06^{aC}	5.16^{dC}

*different small letters in rows indicates significant ($P<0.05$) difference due to pre-treatments
*different capital letters in columns indicates significant ($P<0.05$) difference due to temperature

4.4 Mathematical Modelling and Drying Kinetics

The thin layer drying kinetics of Bitter gourd were analysed for Five frequently used models. The experimental and predicted moisture ratio curve fitting for samples dried at 50, 60 and 70ºC are shown in Fig 4.19-4.21. R^2, RMSE and SSE for all models at 70ºC,60ºC and 50ºC are given in Table 4.7-4.9. The best fit models with all constant values are given in Table 4.10. Among all the models, Page model gave the best drying characteristics of Bitter gourd dried at 50ºC, 60ºC and 70ºC. R^2, RMSE and SSE for all samples ranged between 0.9922 -0.9995, 0.0062- 0.0280, 0.0010-0.0204; 0.9977-0.9998, 0.0076-0.0152, 0.0003-0. 0.0130; 0.9962-0.9984, 0.0128-0.0200, 0.0026-0.0064 respectively for 50, 60 and 70ºC.

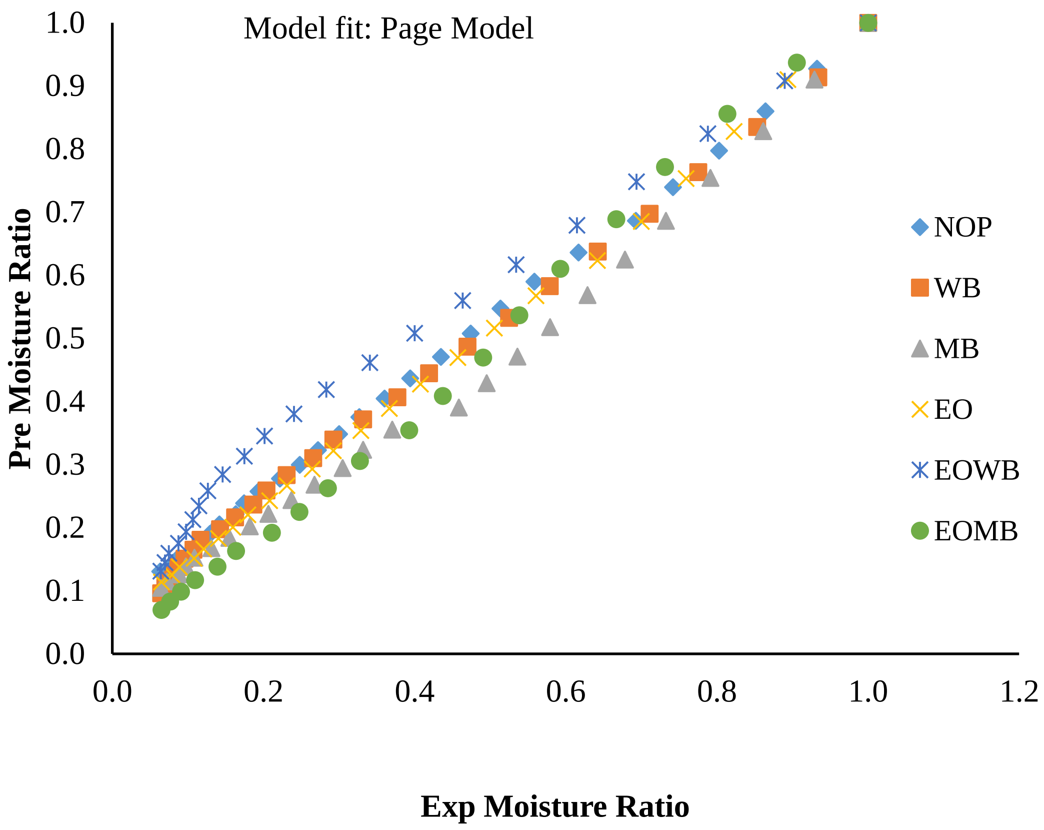

Figure 4.19: Experimental and predicted moisture ratio at 50ºC

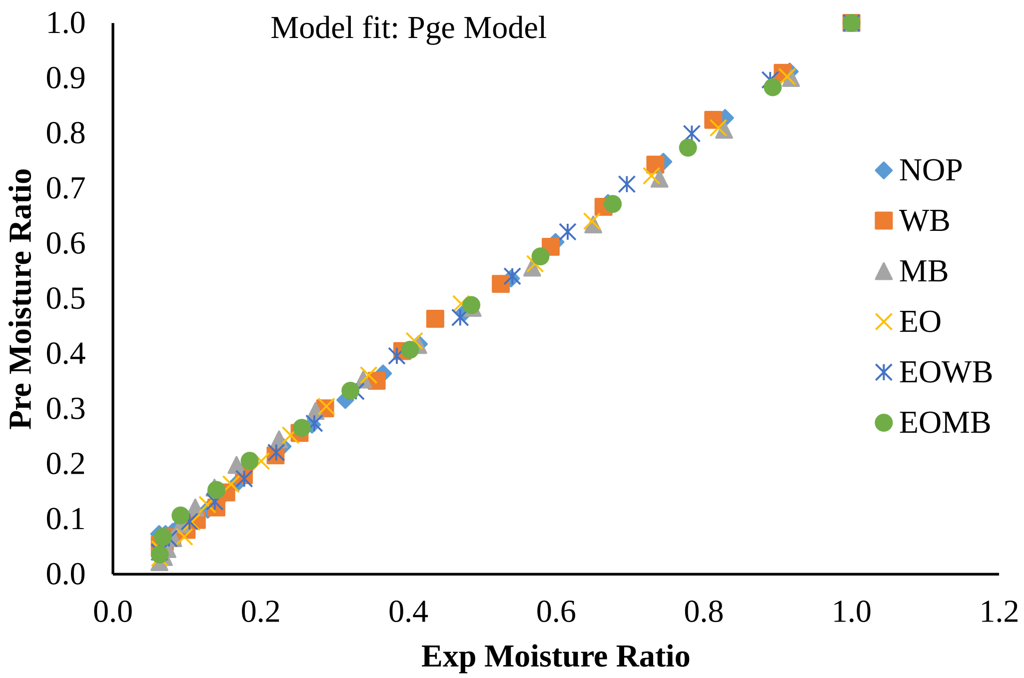

Figure 4.20: Experimental and predicted moisture ratio at 60ºC

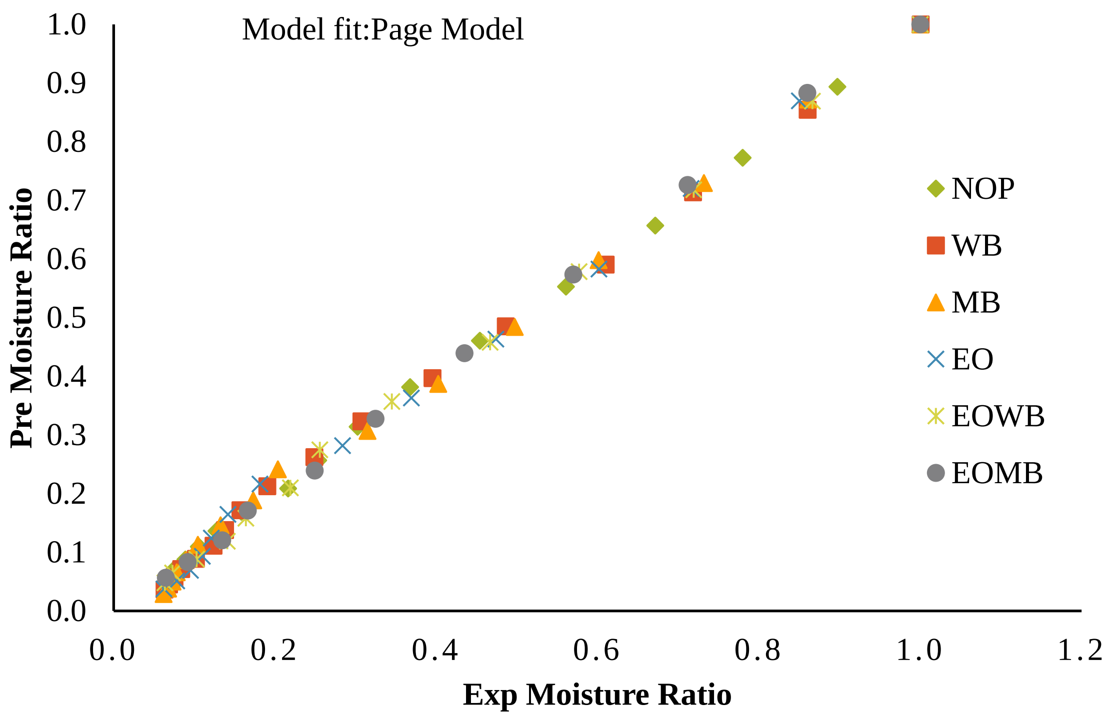

Figure 4.21: Experimental and predicted moisture ratio at 70ºC

Table 4.7: R^2, SSE and RMSE values for selected models for at 70ºC

Model	**Sample**	**Drying temperature**	**R^2**	**SSE**	**RMSE**
Page			0.9984	0.0026	0.0128
Newton			0.9891	0.0177	0.0322
Henderson and Pabis	NOP	70ºC	0.9932	0.0110	0.0262
Logarithmic			0.9948	0.0085	0.0238
Wang and Singh			0.9980	0.0032	0.0142
Page			0.9971	0.0045	0.0167
Newton			0.9945	0.0085	0.0223
Henderson and Pabis	WB	70ºC	0.9958	0.0065	0.0202
Logarithmic			0.9960	0.0062	0.0203
Wang and Singh			0.9854	0.0225	0.0375
Page			0.9965	0.0059	0.0192
Newton			0.9879	0.0201	0.0344
Henderson and Pabis	MB	70ºC	0.9908	0.0153	0.0310
Logarithmic			0.9932	0.0113	0.0274
Wang and Singh			0.9877	0.0205	0.0358
Page			0.9962	0.0064	0.0200
Newton			0.9859	0.0240	0.0376
Henderson and Pabis	EO	70ºC	0.9889	0.0189	0.0344
Logarithmic			0.9963	0.0108	0.0269
Wang and Singh			0.9860	0.0238	0.0386
Page			0.9976	0.0042	0.0161
Newton			0.9863	0.0237	0.0373
Henderson and Pabis	EOWB	70ºC	0.9900	0.0174	0.0330
Logarithmic			0.9962	0.0066	0.0210
Wang and Singh			0.9895	0.0182	0.0338
Page			0.9981	0.0034	0.0150
Newton			0.9793	0.0374	0.0469
Henderson and Pabis	EOMB	70ºC	0.9843	0.0284	0.0421
Logarithmic			0.9931	0.0125	0.0288
Wang and Singh			0.9933	0.0121	0.0275

Table 4.8: R^2, SSE and RMSE values for selected models at 60ºC

Model	**Sample**	**Drying temperature**	**R^2**	**SSE**	**RMSE**
Page			0.9998	0.0003	0.0040
Newton			0.9897	0.0192	0.0302
Henderson and Pabis	NOP	60ºC	0.9932	0.0126	0.0251
Logarithmic			0.9980	0.0037	0.0140
Wang and Singh			0.9997	0.0005	0.0054
Page			0.9977	0.0044	0.0148
Newton			0.9880	0.0228	0.0330
Henderson and Pabis	WB	60ºC	0.9912	0.0168	0.0290
Logarithmic			0.9879	0.0141	0.0186
Wang and Singh			0.9970	0.0057	0.0168
Page			0.9979	0.0046	0.0152
Newton			0.9745	0.0554	0.0514
Henderson and Pabis	MB	60ºC	0.9826	0.0380	0.0436
Logarithmic			0.9949	0.0146	0.0273
Wang and Singh			0.9955	0.0097	0.0220
Page			0.9979	0.0045	0.0150
Newton			0.9766	0.0503	0.0490
Henderson and Pabis	EO	60ºC	0.9833	0.0359	0.0424
Logarithmic			0.9970	0.0064	0.0184
Wang and Singh			0.9978	0.0048	0.0155
Page			0.9995	0.0130	0.0076
Newton			0.9748	0.0544	0.0509
Henderson and Pabis	EOWB	60ºC	0.9795	0.0442	0.0427
Logarithmic			0.9963	0.0080	0.0205
Wang and Singh			0.9991	0.0019	0.0098
Page			0.9987	0.0031	0.0124
Newton			0.9716	0.0635	0.0550
Henderson and Pabis	EOMB	60ºC	0.9783	0.0484	0.0492
Logarithmic			0.9914	0.0191	0.0317
Wang and Singh			0.9980	0.0046	0.0151

Table 4.9: R^2, SSE and RMSE values for selected models at 50ºC

Model	**Sample**	**Drying temperature**	**R^2**	**SSE**	**RMSE**
Page			0.9995	0.0010	0.0062
Newton			0.9948	0.0114	0.0205
Henderson and Pabis	NOP	50ºC	0.9968	0.0069	0.0162
Logarithmic			0.994	0.0013	0.0071
Wang and Singh			0.9981	0.0042	0.0127
Page			0.9989	0.0027	0.0101
Newton			0.9919	0.0189	0.0265
Henderson and Pabis	WB	50ºC	0.9950	0.0116	0.0211
Logarithmic			0.9980	0.0046	0.0136
Wang and Singh			0.9962	0.0089	0.0185
Page			0.9937	0.0160	0.0248
Newton			0.9752	0.0629	0.0483
Henderson and Pabis	MB	50ºC	0.9804	0.0495	0.0437
Logarithmic			0.9926	0.0255	0.0348
Wang and Singh			0.9928	0.0253	0.0343
Page			0.9943	0.0136	0.0229
Newton			0.9873	0.0300	0.0334
Henderson and Pabis	EO	50ºC	0.9885	0.0263	0.318
Logarithmic			0.9942	0.0137	0.0231
Wang and Singh			0.9924	0.0181	0.0264
Page			0.9972	0.0064	0.0157
Newton			0.9934	0.0155	0.0240
Henderson and Pabis	EOWB	50ºC	0.9947	0.0123	0.0218
Logarithmic			0.9972	0.0065	0.0161
Wang and Singh			0.9775	0.0525	0.0449
Page			0.9922	0.0204	0.0280
Newton			0.9772	0.0595	0.0469
Henderson and Pabis	EOMB	50ºC	0.9807	0.0502	0.0440
Logarithmic			0.9919	0.0210	0.0283
Wang and Singh			0.9877	0.0360	0.0311

Table 4.10: The best model fit and constant values

Samples	Drying temperature	R^2	SSE	RMSE	k	n
NOP	70ºC	0.9984	0.0026	0.0128	0.007143	1.198
WB		0.9971	0.0045	0.0167	0.012500	1.100
MB		0.9965	0.0059	0.0192	0.008616	1.202
EO		0.9962	0.0064	0.0200	0.008240	1.230
EOWB		0.9976	0.0042	0.0161	0.008124	1.238
EOMB		0.9981	0.0034	0.0150	0.005373	1.364
NOP	60ºC	0.9998	0.0003	0.0040	0.004886	1.190
WB		0.9977	0.0044	0.0148	0.005076	1.193
MB		0.9979	0.0046	0.0152	0.002967	1.350
EO		0.9979	0.0045	0.0150	0.003373	1.317
EOWB		0.9995	0.0130	0.0076	0.002962	1.415
EOMB		0.9987	0.0031	0.0124	0.002542	1.452
NOP	50ºC	0.9995	0.0010	0.0062	0.007535	1.124
WB		0.9989	0.0027	0.0101	0.009002	1.158
MB		0.9937	0.0160	0.0248	0.009404	1.282
EO		0.9943	0.0136	0.0229	0.009443	1.159
EOWB		0.9972	0.0064	0.0157	0.009666	1.124
EOMB		0.9922	0.0204	0.0280	0.003547	1.262

4.5 Effects of pre-treatments and drying temperature on Quality Parameters

4.5.1 Effect on Colour values, Chroma and Hue angle

The colour values for fresh and pre-treated Bitter gourds are shown in Fig. 4.22-4.24. “L” value towards 100 indicates whiteness, “negative a” value indicates greenness whereas “positive b” value indicates the yellowness of Bitter gourd. The fresh Bitter gourd has L, a, b values of 36.20, -7.63 and 24.39 respectively. NOP, WB and MB samples did not retain the color. Treatment of ethyl oleate and its combination with blanching retained the maximum greenness (-a) after drying. The maximum greenness (-5.04) was obtained in EOWB sample at 50ºC. The retention of colour is maximum at lower temperature. All pre-treated Bitter gourds dried at 70ºC is shown in Fig 4.25-4.30.

The total color change, Chroma and Hue angle for all samples are given in Table 4.11. Combination of ethyl oleate and blanching significantly (P<0.05) affected the color change. The minimum color change was observed in EO treated samples dried at three different temperatures. There is no significant (P>0.05) effect of pre-treatment and temperature on Chroma and Hue angle. Ethyl oleate did not have any positive effect of Chroma and hue angle of dried Bitter gourd (Taser *et al.,* 2007)

Table 4.11: Total color change(ΔE), Chroma and Hue angle values

Pre-treatments	**Drying temperature**	**Total color change (ΔE)**	**Chroma**	**Hue angle**
NOP	50ºC	12.93	17.04	178.45
WB		11.31	16.24	181.55
MB		11.72	16.84	181.49
EO		9.83	17.24	178.64
EOWB		11.63	17.95	178.71
EOMB		11.11	18.33	178.55
NOP	60ºC	13.19	19.49	181.52
WB		13.64	15.88	181.44
MB		11.73	16.98	181.48
EO		9.08	17.38	178.58
EOWB		11.82	18.49	178.43
EOMB		14.04	14.86	178.64
NOP	70ºC	13.25	17.45	181.45
WB		12.24	17.69	181.45
MB		12.38	17.86	181.47
EO		7.50	19.25	178.57
EOWB		10.10	17.14	178.60
EOMB		13.45	14.82	178.66

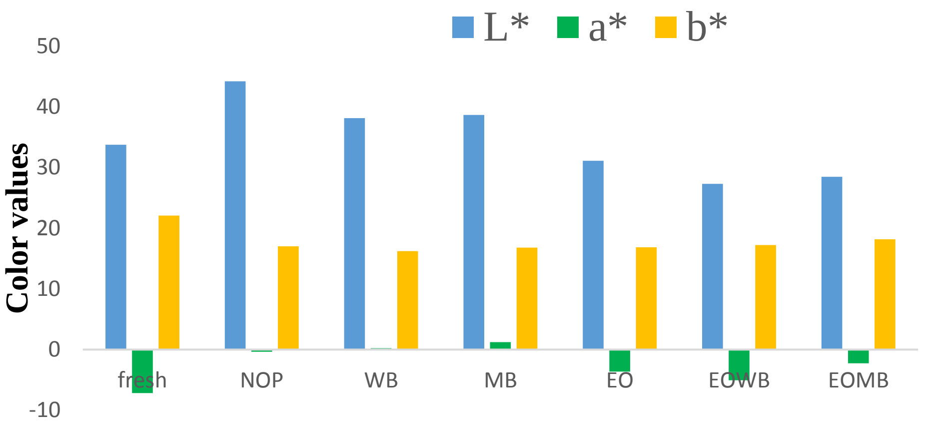

Figure 4.22: Color values for fresh and pre-treated Bitter gourd dried at 50ºC

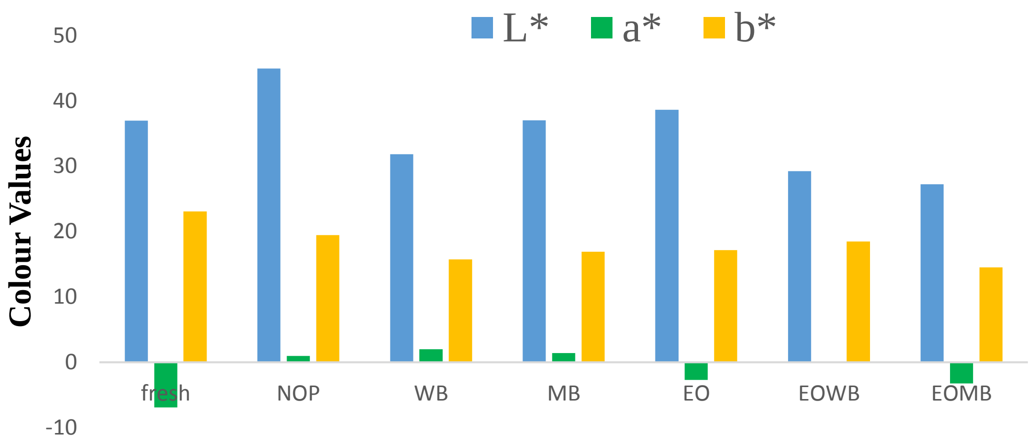

Figure 4.23: Color values for fresh and pre-treated Bitter gourd dried at 60ºC

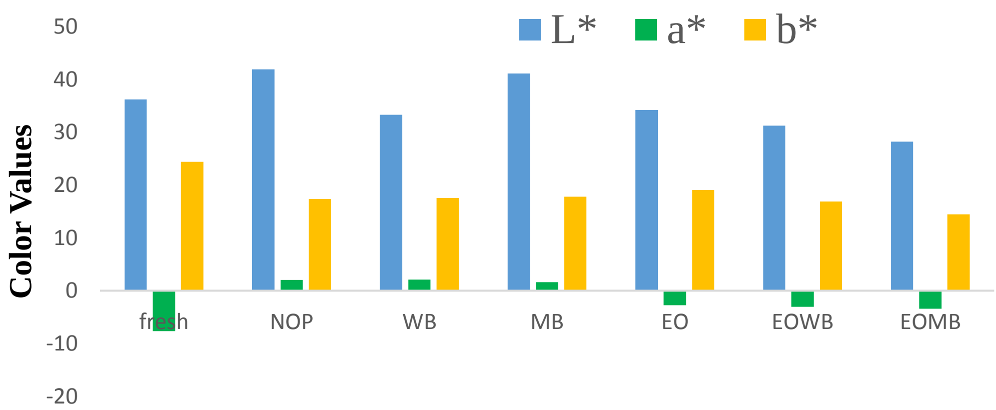

Figure 4.24: Color values for fresh and pre-treated Bitter gourd dried at 70ºC

Figure 4.25: NOP sample dried at 70ºC

Figure 4.26: EO sample dried at 70ºC

Figure 4.27: WB sample dried at 70ºC

Figure 4.28: EOWB sample dried at 70ºC

Figure 4.29: MB sample dried at 70ºC

Figure 4.30: EOMB sample dried at 70ºC

4.5.2 Effect on Vitamin C Content

The combined effect of pre-treatment and drying temperature on vitamin C is given in Table 4.12. Fresh Bitter gourd has higher (94 mg/100g) vitamin C than those reported by Myojin *et al*. (2008). Ethyl oleate treated water blanching and microwave blanching significantly (P<0.05) retained the Vitamin C of dried sample. The pre-treatment of ethyl oleate dipping and subsequent microwave blanching retained the maximum vitamin C (84.34 mg/100g) whereas the not pre-treated samples retained 64.69 mg/100g at 50ºC.

The temperature significantly(P<0.05) affected the vitamin C. As the temperature increased from 50 to 70ºC, vitamin C was reduced from 64.69 to 41.61 mg/100g which is similar to the results that are reported for other vegetables (Njoku *et al*., 2011).

Table 4.12: Effect of pre-treatment and drying temperature on vitamin C

Pre-treatment/temperature	**NOP**	**EOWB**	**EOMB**
50ºC	64.69 ± 0.36^{aA}	74.16 ± 0.15^{bA}	84.34 ± 0.17^{cA}
60ºC	54.02 ± 0.06^{aB}	71.14 ± 0.09^{bB}	80.14 ± 0.09^{cB}
70ºC	41.61 ± 0.05^{aC}	65.25 ± 0.15^{bC}	74.25 ± 0.56^{cC}

* different small letters in a column indicates significant (p<0.05) effect due to pre-treatments
* different capital letters in a row indicates significant (p<0.05) effect due to temperature

4.5.3 Effect on Total phenolic component (TPC)

Total phenolic compound of fresh Bitter gourd is 6.89 mg of GAE/100g which is higher than those reported by Choo *et al*. (2014) i.e. 5.92 mg/100g. The effect of pre-treatments at varied drying temperature is given in Table 4.13. The effect of ethyl oleate and subsequent blanching (hot water and microwave) significantly (P<0.05) increased the TPC. The highest TPC (33.03 mg of GAE/100g) was found in ethyl oleate treated and microwave blanched sample at 60ºC whereas the not pre-treated sample was 9.87 mg of GAE/100g. The drying temperature had significant (P<0.05) effect on TPC.

The increase in temperature from 50 to 60ºC increased the TPC from 9.87 to 21.34 mg of GAE/100g. Aminah and Permatasari (2013) reported that the increase in temperature breaks down the cellular constituents and thus releasing the more phenolic compounds from the sample. The increase in phenolic compounds highly increases the antioxidant capacities.

However, the further increase in temperature decreased the TPC for all samples. These results were matched with Tan *et al*. (2008) who reported the TPC value of Bitter gourd dried at 40, 50 and 60ºC were 1533, 1925 and 1847 mg of GAE/100 g respectively. This is due to the processing at higher temperature releases the hydrolytic and oxidative enzymes destroys the antioxidant activity (Chism and Haard 1996).

Table 4.13: Effect of pre-treatment and drying temperature on TPC

Pre-treatment/temperature	**NOP**	**EOWB**	**EOMB**
50ºC	9.87 ± 0.03^{aA}	13.93 ± 0.54^{bA}	29.67 ± 0.39^{cA}
60ºC	21.34 ± 0.17^{aB}	22.18 ± 0.09^{bB}	33.03 ± 0.27^{cB}
70ºC	7.35 ± 0.17^{aC}	8.47 ± 0.15^{bC}	9.59 ± 0.05^{cC}

* different small letters in the columns indicates significant (p<0.05) effect of pre-treatments
* different capital letters in the rows indicates significant (p<0.05) effect of temperature

4.5.4 Effect on Dipheny Picryl Hydrazyl (DPPH)

The effect of pre-treatments and drying temperature on DPPH is given in Table 4.14. The fresh Bitter gourd had 85.98% of scavenging activity which is higher than those reported by Hamissou *et al*. (2013) i.e. 82.05%. The pre-treatments significantly (P<0.0.5) affected the DPPH of dried Bitter gourd. Ethyl oleate treated water blanching reduced the DDPH activity due to leaching at higher temperature (Nurhuda *et al*. 2013). But, ethyl oleate treated microwave blanching retained the higher antioxidant activity 81.39 % whereas not pre-treated sample retained 80.12% at 50ºC. The temperature had significant effect on DPPH scavenging activity. The increase in temperature from 50 to 70ºC decreased the antioxidant activity from 80.12 to 75.44 % respectively. Tan *et al*. (2013) reported the same results during Bitter gourd drying at varied temperature (40 to 60ºC). Bitter gourd dried at 50 and 60ºC showed no statistical significant (P>0.05) difference on DPPH.

Table 4.14: Effect of pre-treatment and drying temperature on DPPH

Pre-treatment/ temperature	**NOP**	**EOWB**	**EOMB**
50ºC	80.12 ± 0.09^{bB}	74.76 ± 0.12^{aB}	81.39 ± 0.19^{cB}
60ºC	78.44 ± 0.02^{bB}	77.28 ± 0.05^{aB}	80.38 ± 0.08^{cB}
70ºC	75.41 ± 0.21^{bA}	71.39 ± 0.21^{aA}	79.98 ± 0.09^{cA}

* different small letters in the columns indicates significant (p<0.05) effect of pre-treatments

* different capital letters in the rows indicates significant (p<0.05) effect of temperature

4.5.5 Effect on Ferric Reducing Antioxidant Power (FRAP)

The combined effect of pre-treatment and temperature on FRAP is given in Table 4.15. FRAP for fresh Bitter gourd was found to be 5233.59 mg of Trolox/100g of DW which is lower than those reported by Tan *et al*. (2013). The pre-treatments significantly (P<0.05) reduced the FRAP activity. Not pre-treated sample had highest FRAP (4945.33 mg of Trolox /100g of DW) at 50ºC. However, EOMB retained the maximum FRAP (2810.52 mg of Trolox /100g of DW) dried at 70ºC due to the short exposure of drying time. These results were similar to findings reported by Aminah and Permatasari (2013) that microwaving significantly retained the higher FRAP values. Drying temperature significantly (P<0.05) affected FRAP value. The increase in temperature decreased the FRAP value for not pre-treated samples from 4945.53 to 4073.68 mg of Trolox/ 100g of DW whereas the FRAP value increased from 512.28 to 2810.52 mg of Trolox/ 100g of DW for EOMB treated samples.

Table 4.15: Effect of pre-treatment and drying temperature on FRAP

Pre-treatment/ temperature	**NOP**	**EOWB**	**EOMB**
50ºC	4945.33 ± 0.07^{cA}	450.87 ± 0.11^{aA}	512.28 ± 0.17^{bA}
60ºC	4843.21 ± 0.12^{cB}	1687.71 ± 0.08^{aB}	1722.80 ± 0.18^{bB}
70ºC	4073.68 ± 0.24^{cC}	2617.54 ± 0.09^{aC}	2810.52 ± 0.10^{bC}

* different small letters in the columns indicates significant (p<0.05) effect of pre-treatments
* different capital letters in the rows indicates significant (p<0.05) effect of temperature

Chapter 5

Summary and Conclusions

Bitter gourd is an internationally consumed vegetable containing high amounts of vitamins and minerals. The vegetable has numerous medicinal and health benefits and is widely recommended in daily diet. Despite of many advantages, proper processing and value addition have not been explored yet. Drying with appropriate pretreatments can extend the shelf life and availability of the product for consumption throughout the year. The present work investigated various physico-chemical and textural properties of Bitter gourd and explores the effects of different pre-treatments on drying characteristics of Bitter gourd.

Conclusion from each objective of this research have been presented in section 5.1 and recommendations for future research are listed in section 5.2.

5.1. Summary and Conclusions

5.1.1. Determination of Physico-chemical and Textural properties of Bitter gourd

Bitter gourd is rich in antioxidants and other nutrients. Despite of all these benefits and high consumer demand, processing of Bitter gourd has not been standardized. There is a need to design and develop processing equipment and operations for efficient value-addition. From a design point of view, it is necessary to know various physical, chemical and textural properties of Bitter gourd to optimize processing equipment and post-harvest operations.

Physical properties such as geometric mean diameter, surface area, sphericity, bulk density etc. were measured following standard methods. Textural properties like hardness, gumminess and springiness etc. were evaluated using texture analyzer. Similarly, chemical composition of Bitter gourd was determined. The authors are of the opinion that these properties of Bitter gourd would add to the scientific knowledge base and help researchers in design and development of appropriate technology for value addition of Bitter gourd. Length, unit mass, surface area, volume and porosity properties shows significant variation ($P<0.05$). These properties increased with size. Other properties did not show significant ($P>0.05$) difference among small, medium and large size Bitter gourd.

The moisture content and Vitamin C was found to be 91% (wb) and 94 mg/100g in Pusa hybrid variety Bitter gourd. Bitter gourd is perishable, there is a need for post-harvest operations to extend its shelflife and the availability of the throughout the year. The texture profile analysis of Bitter gourd shows maximum and minimum hardness of 81 N and 41 N respectively. There is a significant difference ($P<0.05$) in textural properties among small, medium and large Bitter gourd.

5.1.2 Effect of pre-treatments on drying characteristics of Bitter gourd

To develop the processing technology of Bitter gourd, the various pre-treatments like water blanching, microwave blanching, ethyl oleate dipping, ethyl oleate treated Water blanching and ethyl oleate treated microwave blanching were followed. The leaching was the major problem in hot water blanching and microwave assisted hot water blanching. To overcome this problem, the authors of this research concentrated on the effect of ethyl oleate and ethyl oleate treated blanching methods on drying of Bitter gourd. No work has been reported on the combined effects.

The optimised condition of time and temperature for an inactivation of enzymes was 80ºC for 3 mins for water blanching. The optimised condition of time and power for microwave blanching was 600 W for 135 s. The alkaline solution of ethyl oleate was optimised as 2% of Ethyl oleate and 4% of potassium carbonate (K_2CO_3).

All the pre-treated and control samples were dried at three different temperatures of 50,60 and 70ºC to the final moisture content of 5-6% from an initial moisture of 90% (wb). There was a significant ($P<0.05$) reduction in drying time with all pre-treatments and drying temperatures. At 70ºC, the not pre-treated samples had maximum (190 min) drying time whereas ethyl oleate treated microwave blanched samples had minimum (100 min) drying time. The percentage reduction in drying time was highest in ethyl oleate treated microwave blanched samples.

Both temperature and pre-treatments significantly ($P<0.05$) increased the moisture diffusivity. Ethyl oleate treated microwave blanched samples increased the effective diffusivity from 3.86 to 7.48 $\times10^{-8}$ m^2/s as the temperature increased from 50 to 70ºC.

Shrinkage and rehydration ratio are the other two important drying characteristics. There was a significant ($P<0.05$) effect of temperature and pre-treatments on shrinkage ratio. The shrinkage ratio was ranged between 70.30 to 80.2 % for not pre-treated samples and 46.04 to 52.06% for ethyl oleate treated microwave blanched samples as the temperature increased from 50 to 70ºC. The rehydration ratio was higher in all pre-treated samples than control samples. The maximum rehydration ratio in ethyl oleate treated microwave blanched treated sample at three different temperatures. There was significant ($P<0.05$) effect of temperature and pre-treatments on rehydration ratio.

5.1.3 Mathematical modelling of dried Bitter gourds

The thin layer drying kinetics of Bitter gourd were analysed with selected five mathematical models. The experimental and predicted moisture ratio curve fitting for samples dried at 50, 60 and 70ºC are done. Among all the models, Page model described the best drying characteristics of Bitter gourd dried at 50, 60 and 70 ºC.

5.1.4 Quality attributes of dried Bitter gourd

Bitter gourd has 94mg/100g (vitamin C), 5.73mg of GAE/100g (Total Phenolic Compounds), 85.98% (2,2, diphenyl picryl hydrazyl) and 5233.59 mg of Trolox/100g of DW (ferric reducing antioxidant power) before pre-treatment. All pre-treatments and drying temperature had significant ($P<0.05$) effect on vitamin C, total phenolic compounds, 2,2, diphenyl picryl hydrazyl and ferric reducing antioxidant power. At 50ºC, the vitamin C for NOP sample was 64.69mg/100g whereas ethyl oleate treated microwave blanched samples had 84.34 mg/100g. Total Phenolic Compounds increased as the temperature increased from 50 to 60ºC but further increase in temperature i.e. at 70ºC TPC decreased. The maximum retention of total phenolic compounds was observed in ethyl oleate treated and microwave blanched samples.

Ethyl oleate treated microwave blanched sample retained the higher antioxidant activity 81.39 % whereas not pre-treated sample retained 80.12% at 50ºC. The pre-treatments and drying temperature significantly ($P<0.05$) reduced the FRAP activity of Bitter gourd. Not pre-treated sample had highest FRAP (4945.33 mg of Trolox /100g of DW) at 50ºC. The increase in temperature decreased the FRAP value from 4945.53 to 4073.68 mg of Trolox/100g of DW for not pre-treated samples.

Pre-treatments and drying temperature did not have significant ($P>0.05$) effect on Chroma and Hue angle. The total colour change was minimum in ethyl oleate treated samples.

Combined pre-treatment of ethyl oleate (2% EO and 4% K_2CO_3) and microwave blanching (600W for 135 seconds) had resulted in most acceptable drying characteristics and quality characteristics of Bitter gourd.

5.2 Recommendations and Future Scope

Some of the important recommendations drawn from this study includes further understanding of the effect of ethyl oleate in foods.

1. Different concentration of ethyl oleate and potassium carbonate, need to be studied
2. The effect of ethyl oleate assisted blanching could be studied on microwave drying characteristics of other fruits and vegetables.

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Dissemination

Conferences

- Srimagal, A., Mishra, S., Pradhan, R. C. 2016. Effect of Ethyl Oleate Treatment on Drying of Bitter gourd. Proceedings of American Society of Agriculture and Biological Engineers, 17-20 July 2016, Orlando, Florida, United States of America.

- Srimagal, A., Mishra, S., Pradhan, R. C. 2016. Physico-chemical properties and value addition of Bitter gourd. Proceedings of 50th Annual Convention of ISAE and Symposium on "Agricultural Engineering in nation Building: Contribution and Chanllenges", 19-21 January 2016, Bhubaneswar, Odisha, India.

Publications

- Srimagal, A., Mishra, S., Pradhan, R. C. 2016. Effect of Ethyl Oleate Treatment on Drying of Bitter gourd. Technical Library, American Society of Agricultural and Biological Engineers. doi: 10.13031/aim.20162461378.

Article under review

- Srimagal, A., Mishra, S., Pradhan, R.C. 2016. Physico-Chemical Properties and Texture Profile Analysis of Bitter gourd. International Food Research Journal (Under review).

- Srimagal, A., Mishra, S., Pradhan, R.C. 2016. Effects of Ethyl Oleate and Microwave Blanching on Drying Kinetics of Bitter gourd. Journal of Food Science and Technology (Under review).

- Srimagal, A., Mishra, S., Pradhan, R.C. 2016. Effect of ethyl oleate assisted drying on antioxidant properties of Bitter gourd (Manuscript under preparation)

Appendix A. ANOVA for Properties

ANOVA for Physical properties

Properties		Sum of Squares	df	Mean Square	F	Sig.
	Between Groups	123.773	2	61.887	18.118	.003
Length	Within Groups	20.495	6	3.416		
	Total	144.268	8			
	Between Groups	1.840	2	.920	.698	.534
Breadth	Within Groups	7.913	6	1.319		
	Total	9.753	8			
	Between Groups	8416.135	2	4208.068	61.531	.000
Mass	Within Groups	410.340	6	68.390		
	Total	8826.475	8			
	Between Groups	1.472	2	.736	4.645	.060
GMD	Within Groups	.951	6	.158		
	Total	2.423	8			
	Between Groups	1.600	2	.800	5.315	.047
AMD	Within Groups	.903	6	.151		
	Total	2.503	8			
	Between Groups	89.139	2	44.570	.842	.476
AR	Within Groups	317.426	6	52.904		
	Total	406.565	8			
	Between Groups	36.108	2	18.054	.385	.696
Sphericity	Within Groups	281.100	6	46.850		
	Total	317.208	8			
	Between Groups	10484.992	2	5242.496	4.206	.072
SA	Within Groups	7478.310	6	1246.385		
	Total	17963.302	8			
	Between Groups	8266.667	2	4133.333	186.000	.000
Volume	Within Groups	133.333	6	22.222		
	Total	8400.000	8			
	Between Groups	.076	2	.038	2.493	.163
BD	Within Groups	.091	6	.015		
	Total	.167	8			
	Between Groups	.001	2	.000	.004	.996
TD	Within Groups	.706	6	.118		
	Total	.706	8			
	Between Groups	26.584	2	13.292	74.610	.000
Porosity	Within Groups	1.069	6	.178		
	Total	27.653	8			
	Between Groups	32.630	2	16.315	3.633	.093
Mild steel	Within Groups	26.947	6	4.491		
	Total	59.577	8			
	Between Groups	.112	2	.056	.065	.938
Glass	Within Groups	5.166	6	.861		
	Total	5.277	8			
	Between Groups	3.507	2	1.754	.215	.812
Plywood	Within Groups	48.823	6	8.137		
	Total	52.330	8			

ANOVA for Textural properties

Properties		Sum of Squares	df	Mean Square	F	Sig.
hardness	Between Groups	2459.747	2	1229.873	96.040	.000
	Within Groups	76.835	6	12.806		
	Total	2536.582	8			
resilience	Between Groups	.001	2	.001	9.571	.014
	Within Groups	.000	6	.000		
	Total	.002	8			
cohesiveness	Between Groups	.006	2	.003	4.421	.066
	Within Groups	.004	6	.001		
	Total	.009	8			
springiness	Between Groups	94.703	2	47.351	25.631	.001
	Within Groups	11.084	6	1.847		
	Total	105.787	8			
gumminess	Between Groups	225.294	2	112.647	31.165	.001
	Within Groups	21.687	6	3.614		
	Total	246.981	8			
chewiness	Between Groups	.141	2	.070	49.078	.000
	Within Groups	.009	6	.001		
	Total	.149	8			

Appendix B. Univariate ANOVA for Drying Characteristics

Tests of Between-Subjects Effects

Dependent Variable: Diffusivity

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	91.160[a]	17	5.362	62949.029	.000
Intercept	1124.040	1	1124.040	13195255.848	.000
pretreatment	25.784	5	5.157	60535.848	.000
temperature	62.279	2	31.139	365548.717	.000
pretreatment * temperature	3.097	10	.310	3635.683	.000
Error	.003	36	8.519E-005		
Total	1215.203	54			
Corrected Total	91.163	53			

a. R Squared = 1.000 (Adjusted R Squared = 1.000)

Tests of Between-Subjects Effects

Dependent Variable: Shrinkage ratio

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	5157.756[a]	17	303.397	1532.611	.000
Intercept	208048.709	1	208048.709	1050957.472	.000
pretreatment	4730.826	5	946.165	4779.551	.000
temperature	405.288	2	202.644	1023.655	.000
pretreatment * temperature	21.642	10	2.164	10.932	.000
Error	7.127	36	.198		
Total	213213.591	54			
Corrected Total	5164.883	53			

a. R Squared = .999 (Adjusted R Squared = .998)

Tests of Between-Subjects Effects

Dependent Variable: Rehydration ratio

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	16.121[a]	17	.948	843.621	.000
Intercept	958.281	1	958.281	852506.596	.000
pretreatment	3.805	5	.761	677.052	.000
temperature	10.736	2	5.368	4775.438	.000
pretreatment * temperature	1.580	10	.158	140.542	.000
Error	.040	36	.001		
Total	974.442	54			
Corrected Total	16.161	53			

a. R Squared = .997 (Adjusted R Squared = .996)

Appendix C. Univariate ANOVA for Quality Characteristics

Tests of Between-Subjects Effects
Dependent Variable: Total colour change

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	161.206[a]	17	9.483	56.393	.000
Intercept	7418.291	1	7418.291	44116.133	.000
pretreatment	115.461	5	23.092	137.328	.000
Temperature	11.281	2	5.640	33.543	.000
pretreatment * Temperature	34.464	10	3.446	20.495	.000
Error	6.054	36	.168		
Total	7585.550	54			
Corrected Total	167.259	53			

a. R Squared = .964 (Adjusted R Squared = .947)

Tests of Between-Subjects Effects
Dependent Variable: Hue angle

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	110.173[a]	17	6.481	228.434	.000
Intercept	1745998.256	1	1745998.256	61543019.452	.000
pretreatment	91.324	5	18.265	643.796	.000
Temperature	3.408	2	1.704	60.060	.000
pretreatment * Temperature	15.441	10	1.544	54.427	.000
Error	1.021	36	.028		
Total	1746109.450	54			
Corrected Total	111.194	53			

a. R Squared = .991 (Adjusted R Squared = .986)

Tests of Between-Subjects Effects

Dependent Variable: Chroma

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	103.406[a]	17	6.083	1188.808	.000
Intercept	16102.894	1	16102.894	3147145.313	.000
pretreatment	77.601	5	15.520	3033.257	.000
Temperature	.666	2	.333	65.056	.000
pretreatment * Temperature	25.140	10	2.514	491.334	.000
Error	.184	36	.005		
Total	16206.484	54			
Corrected Total	103.591	53			

a. R Squared = .998 (Adjusted R Squared = .997)

Tests of Between-Subjects Effects

Dependent Variable: Vitamin C

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	4248.699[a]	8	531.087	8703.179	.000
Intercept	123774.557	1	123774.557	2028352.178	.000
pretreatment	3220.998	2	1610.499	26392.012	.000
temperature	840.249	2	420.125	6884.781	.000
pretreatment * temperature	187.451	4	46.863	767.961	.000
Error	1.098	18	.061		
Total	128024.354	27			
Corrected Total	4249.797	26			

Tests of Between-Subjects Effects

Dependent Variable: Total Phenolic Compound

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	2214.909[a]	8	276.864	3903.765	.000
Intercept	7891.650	1	7891.650	111271.899	.000
pretreatment	647.097	2	323.549	4562.019	.000
temperature	1303.583	2	651.792	9190.233	.000
pretreatment * temperature	264.229	4	66.057	931.403	.000
Error	1.277	18	.071		
Total	10107.836	27			
Corrected Total	2216.186	26			

Tests of Between-Subjects Effects

Dependent Variable: 2,2, Diphenyl Picryl Hydrazyl

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	262.258[a]	8	32.782	1738.942	.000
Intercept	162511.481	1	162511.481	8620451.835	.000
pretreatment	168.938	2	84.469	4480.683	.000
Temperature	61.163	2	30.582	1622.213	.000
pretreatment * Temperature	32.157	4	8.039	426.437	.000
Error	.339	18	.019		
Total	162774.079	27			
Corrected Total	262.598	26			

Tests of Between-Subjects Effects

Dependent Variable: Ferric reducing antioxidant power

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Corrected Model	69833061.974[a]	8	8729132.747	153332.487	.000
Intercept	186045142.504	1	186045142.504	3267995.260	.000
pretreatment	53383010.323	2	26691505.161	468852.404	.000
Temperature	6680661.461	2	3340330.730	58674.926	.000
pretreatment * Temperature	9769390.191	4	2442347.548	42901.309	.000
Error	1024.730	18	56.929		
Total	255879229.208	27			
Corrected Total	69834086.704	26			

RESUME

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Academic Qualification

- Master of Technology (Research)- Food Process Engineering in National Institute of Technology (NIT), Rourkela, Odisha with **9.08/10.00** CGPA in 2016 (present)
- Bachelor of Technology -Food Process Engineering in Indian Institute of Crop Processing Technology (IICPT), MOFPI, Tanjore, Tamilnadu with **9.02/10.00** OGPA in 2014
- Higher secondary in Achariya Siksha Mandir, Puducherry with **92%** in 2010
- Secondary education in Sri Sampourna Vidyalaya, Puducherry with **96%** in 2008

Awards and Achievements

- Dr. Subramaniam MAIP travel award for an international study visit - Kesetsart University, Thailand, 2014
- Won 1st place in poster competition in the Emerging Technologies in Agricultural Engineering held at Kumulur, 2013
- Won 3rd place in poster presentation in the National Symposium held at SRM university in association with AFSTI, 2013.
- Awarded with Institute merit cum mean scholarship for consecutive three years in IICPT.
- Won 3rd place in poster presentation in the National Seminar at Tamil Nadu Agricultural University (TNAU), 2011.
- Awarded with Gold coins for meritorious performance in the secondary education, 2008

Research experience

- Master's programme: Effect of Pre-treatments on Drying Characteristics of Bitter gourd
- Bachelor's programme: Effect of Light Emitting Diode (LED) treatment on inactivation of Escherichia Coli in milk,2014
- Summer Intern project: Effect of pre-treatments and drying temperature on retention of capsaicin and color of green chili powder,2013

Conference and seminars

- Presented posters in 3 International conferences and **7** National conferences
- Attended one-day workshop on Intellectual Property and Innovation Management in Knowledge Era organized by National Institute of Technology, Rourkela in collaboration with National Research Development Corporation ,2015

Paper publications

- Effect of Light Emitting Diode treatment on Inactivation of Escherichia coli in milk. *LWT-Food Science and Technology.*
- Srimagal, A., Mishra, S., Pradhan, R. C. 2016. Effect of Ethyl Oleate Treatment on Drying of Bitter gourd. Technical Library, American Society of Agricultural and Biological Engineers. doi: 10.13031/aim.20162461378

Skills and Abilities

- Good presentation skills, team work capability, managerial skills, leadership quality and computer software skills